Graduate Studies

UNIVERSITY OF ALBERTA

AN EVALUATION OF THE MODIFIED ASTRAND-RYHMING NOMOGRAM AS AN ESTIMATOR OF MAXIMAL OXYGEN CONSUMPTION

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR
THE DEGREE MASTER OF SCIENCE

FACULTY OF PHYSICAL EDUCATION
by
GERALD H. BAYCROFT

August, 1964

APPROVAL SHEET

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "An Evaluation of the Modified Astrand - Ryhming Nomogram as an Estimator of Maximal Oxygen Consumption", submitted by Gerald H. Y. Baycroft in partial fulfilment of the requirements for the Degree of Master of Science.

ABSTRACT

Forty-eight physically active males were used to evaluate the modified Astrand-Ryhming Nomogram as a predictor of Maximal oxygen consumption. In addition to the modified Astrand Bicycle Ergometer test of Maximal Oxygen Uptake and the Mitchell, Sproule and Chapman Maximal Oxygen Intake test, body height, weight and surface area as well as fitness scores and time run on the Johnson, Brouha and Darling test of Physical Fitness were studied.

Oxygen uptake tests were performed in definite sequences and subjects were equally divided by chance into all possible orders. Gas analyses were performed using a Beckman E-2 oxygen analyser and a Godart Capnograph carbon dioxide analyser and checked by the Scholander method. Results were analysed with Pearson Product-moment correlation coefficients and analysis of variance.

Results obtained were: In terms of liters per minute, the modified Astrand-Ryhming nomogram produced significant correlations ($p = .01$) of 0.67 with the Mitchell, et al test, and 0.62 with the modified Astrand Bicycle test. The treadmill test correlated 0.51 with the maximal bicycle test. With body weight partialled out the correlations were again significant ($p = .01$) and equal to 0.53, 0.47, and 0.39 respectively.

Fitness scores on the Johnson, Brouha and Darling test produced significant correlations ($p = .01$) of 0.38 with the treadmill test, 0.46 with the maximal bicycle test, and 0.55 with the predicted test in terms of liters per minute. Corresponding values in milliliters per kilogram of body weight per minute were 0.46, 0.55, and 0.67 respectively.

Height correlated significantly with the Astrand Bicycle test ($p = .01$), the Mitchell, et al test ($p = .05$) and the predictive test ($p = .05$) in terms of liters per minute.

Weight and body surface area produced equivalent results which were significant with all three of the oxygen consumption tests in terms of liters per minute ($p = .01$) and with the two actual tests (negative relationship)

in terms of milliliters per kilogram of body weight per minute ($p = .05$).

Fitness scores and endurance measured on the Johnson, et al test did not correlate significantly with height, weight, or body surface area.

Within the limits of this study, the following conclusions have been made:

1. For the population studied, the Mitchell, Sproule and Chapman Maximal Oxygen Intake test and the modified Astrand-Ryhming Nomogram for Prediction of Maximal Oxygen Uptake, yielded significantly higher mean values than the modified Astrand Bicycle Ergometer test of Maximal Oxygen Uptake.

2. Statistically equivalent means were obtained on the modified Astrand-Ryhming Nomogram and the Mitchell, Sproule and Chapman Maximal Oxygen Intake test.

3. The Astrand-Ryhming Nomogram produced a significantly greater variance than did the modified Astrand Bicycle Ergometer test and the Mitchell, Sproule and Chapman test.

4. The Astrand-Ryhming Nomogram was able to predict maximal oxygen intake values on the modified Astrand Bicycle Ergometer test and the Mitchell, Sproule and Chapman test as well as the latter tests were able to predict values on each other.

5. As measured by the Johnson, Brouha and Darling test of Physical Fitness, the Astrand-Ryhming Nomogram was able to predict physical fitness as well as the modified Astrand Bicycle Ergometer test and significantly better than the Mitchell, Sproule and Chapman test.

6. Body weight and surface area produced equivalent significant correlations with the three test of maximal oxygen uptake in terms of liters of oxygen consumed per minute.

7. Body height, weight and surface area did not show any significant relationships with the Johnson, Brouha and Darling fitness index or endurance.

8. Correlation coefficients involving body weight and body surface area proved to be virtually identical.

ACKNOWLEDGMENT

Together we stand! As brothers we will go forward into knowledge, searching in every possible niche for the grains of truth and the realization of each worthwhile goal in life.

The author cannot help being overwhelmed by the concern for detail and unstinting comradship of Gerry Glassford and Tony Sedgwick, his co-workers. It was a joy to work with you, fellows!

The personal concern and sacrifice of Dr. Ross Macnab, my chairman, and the encouraging assistances and criticisms of my committee, Dr. B.J. Sproule, Dr. M.L. Howell and Dr. M.L. Van Vliet will long be remembered.

To all those who subjected themselves to the rigors of testing, my heartfelt thanks and may you all be richer from the experience.

Most of all I am grateful to my parents for their years of sacrifice, love and support.

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS USED

In recent years exercise physiologists have put much faith in the measurement of maximal oxygen intake (aerobic capacity) as a good estimation of physical working capacity (7, 45, 82). It is believed that the relationship involves the efficiency of the cardio-respiratory system to take up, transport and give off oxygen for use by body tissues (10, 61). Accurate measurement of this efficiency is purported to be the best objective measure of physical fitness, as revealed by the cardio-respiratory system (12, 52, 61, 63, 86). Many different methods of assessing aerobic capacity are being currently used (10, 61, 82, 88). These are reported to be highly standardized and reliable by investigators (12). The question is, do such methods produce equivalent values of maximal oxygen intake?

Since these methods are time-consuming and costly in terms of equipment and subjects, tests of a submaximal nature have been developed to estimate an individual's aerobic capacity (3, 11, 27, 50, 76, 88, 91). Values obtained from tests by Sjöstrand (76) and Astrand-Ryhming (11), as reported by de Vries, et al (34), have a high correlation with those obtained in maximal tests. It is possible that such submaximal tests are as good at predicting maximal oxygen intake as the maximal tests are at measuring it. It is also possible that submaximal tests could correlate as well with maximal tests as these measures of aerobic capacity do with each other.

Statement of the Problem. It is the purpose of this study to evaluate the Modified Astrand-Ryhming Nomogram for the Prediction of Maximal Oxygen Uptake From Submaximal Work (3, 11), as an estimator of aerobic capacity in terms of two actual tests. These tests are: The Mitchell, Sproule and Chapman Maximal Oxygen Intake Test (61), and the Astrand Bicycle Ergometer Test of Maximal Oxygen Uptake (5, 7, 10).

Subsidiary Problems. It is also a purpose of this study to evaluate each of the above measures in terms of:

1. Endurance (time run) and the Physical Fitness Score on the Johnson, Brouha and Darling Test of Physical Fitness (51).

2. Height, Weight, and Surface Area of each subject.

The Null Hypothesis. In this study, the null hypothesis asserts that there are no significant differences between the means obtained on the tests studied.

$$H_0: u_1 = u_2 = u_3$$

Justification of the Study. It seems evident from the previous discussion that an accurate comparison of the values obtained from a number of maximal oxygen intake tests is needed before evaluation of results from each of these tests can be considered valuable. The tests that will be compared in this study are widely used and differ in their methods of application. Binkhorst and van Leeuwen (15:465) state, "Research must be continued to find out more about the results obtained with various function tests for the determination of aerobic capacity". They go on to say, "A closer examination of these and other criteria seems urgently needed to clarify the real spread of the methods ... " (15:465). If these tests are valid measures of maximal oxygen intake they should produce equivalent values.

As stated earlier, if a test of submaximal work capacity is able to predict an individual's maximal oxygen uptake as well as actual tests are able to predict scores on each other then much time, expense and subject inconvenience could be saved by using it.

Most depth studies of maximal oxygen intake are done on small samples of the population (Astrand and Saltin (12) 1961, N = 7; Newton (63) 1963, N = 7, deVries and Klafs (34) 1964, N = 16). A study involving a large number of individuals could make results more meaningful.

Limitations of the Study.

1. The study is limited to 48 male subjects including active university students and staff members, and both active and sedentary army personnel.

2. Only the parameters stated in the problem and subsidiary problems are considered.

3. The study is limited by the reliabilities of the methods employed and by the limitations of the equipment utilized.

4. The experimental errors of the investigator will limit the study.

5. The statistical procedures used will limit the study.

Definitions of Terms Used.

Maximal Oxygen Intake (aerobic capacity): Hill (44:115) has stated that maximal oxygen intake is reached when, "the oxygen intake per unit time reaches its maximum and remains constant ... owing to the limitation of the circulatory and respiratory systems". Mitchell, Sproule and Chapman (61:538) state that,

> When one subjects a normal individual to progressively increasing workloads ... a linear relationship between workload and oxygen intake is found. Ultimately, maximal oxygen intake per unit of time is reached; beyond this point the workload can usually be increased ... but oxygen intake levels off or declines .

In the tests used, this state is said to have occurred when a measurement of maximal oxygen consumption does not exceed the preceding measure by: (a) 54 ml/min in the Mitchell, Sproule and Chapman Maximal Oxygen Intake Test (61:539), and (b) 81 ml/min. in the Astrand Bicycle Ergometer Test of Maximal Oxygen Uptake (6).

Steady State: A steady state is a period of adaptation to work that results in two consecutive measures of heart rate that differ by $\pm$ 5 beats per minute or less after the fifth minute of exercise as used in the Modified Astrand-Ryhming Nomogram for Prediction of Maximal Oxygen Uptake (11).

Maximal and Submaximal Work: Maximal work is the greatest amount of physical work that a subject is able to perform before exhaustion or fatigue force termination. Any amount less than this is termed submaximal.

Endurance: Endurance is the time, in seconds, that a subject is able to run (up to a maximum of 5 minutes) on a motor driven treadmill at a speed of 7 mph and a grade of 8.6%, according to the procedure of Johnson, Brouha and Darling (51).

Kilopond Meter (Kpm): One kilopond meter is the force acting on a mass of one kilogram at the normal acceleration of gravity (85).

CHAPTER II

REVIEW OF THE LITERATURE

"It is generally agreed by work physiologists that the capacity to perform long continued physical work in a temperate environment is related to the capacity of the cardiovascular respiratory system to deliver oxygen to the muscles (the maximal oxygen intake)" (84:704), (7, 69, 82). It has also been shown that work at submaximal levels has a direct relationship to both oxygen uptake and heart rate (11, 34, 94). This relationship has been used to estimate work capacity, pulmonary efficiency and cardiac capacity (14, 24, 59, 88). Cardiovascular-respiratory performance has also been studied in relationship to age (3, 6, 7, 30, 66), sex (6, 7, 30), and other parameters (30).

Oxygen Consumption: Oxygen consumption is the rate at which the body uses oxygen and according to many authors it is directly determined by work requirements at submaximal workloads (7, 37, 63, 84). As maximal workloads are reached, two processes enable work to be carried on. These are aerobic mechanisms using atmospheric oxygen, and anaerobic mechanisms using oxygen stores within the body. Huckabee and Judson (49) state that anaerobic processes begin only after the aerobic capacity has been reached. This aerobic capacity (maximal oxygen intake), according to Wyndham and Ward (95), is limited by the cardiovascular system's ability to take up, transport and give off oxygen to the tissues. Evidence is given that the pulmonary system reaches its maximum ventilation during submaximal levels (40, 95). Taylor and Brozek (81) add that measurement of this aerobic capacity is the best available test of the function of the cardiovascular-respiratory system. Several authors (6, 61, 63) agree that aerobic capacity is the maximal amount of oxygen that can be utilized by the body in a given period of time, as limited by the cardiovascular-respiratory system. It is not determined by workload because anaerobic mechanisms allow greater

amounts of work to be accomplished. Working ability and rate of work however, can be largely determined by aerobic capacity as the following statements imply:

Astrand (7:308),

> ... the individual's capacity for oxygen intake should be decisive in determining his ability to sustain heavy, prolonged work.

Newton (63:164),

> the maximal oxygen intake is the best single physiological indicator of the capacity of a man for sustaining hard work.

In addition to this, Hettinger, et al (45) state that the maximal oxygen intake is the best measure of an individual's "physical fitness" or capacity to perform heavy work. Newton also stated of maximal oxygen consumption (63:165) "it is the most objective measure by which one gains insight into the physical fitness of an individual as reflected by his cardiovascular system".

Variation in Maximal Oxygen Intake: Inter-individual differences have shown a wide range of values with Robinson (69) reporting a high of 5.35 liters per minute and Astrand (5) a low of 0.74 liters per minute. Taylor, et al (84) report the range as being from about 30 to 81 cc per kilogram of body weight per minute. Astrand and Saltin also studied intra-individual variations when using a variety of methods for determining maximal oxygen intake (12). Their main findings were that enough muscle groups must become involved and the work must be strenuous enough to tax the limit of the cardiovascular-respiratory system. For example, they obtained higher maximal oxygen intake values for running on an inclined treadmill (7.9 percent) than for running at the same speed on a level treadmill. It was also noted that running on a treadmill produced a significantly higher maximal oxygen intake value (P = .05) than did cycling on a bicycle

ergometer (12:979).

Newton (63) also compared different methods of determining aerobic capacity using a Balke modification, the Cureton all-out run, an individually adjusted treadmill test, and a bicycle ergometer test. With seven subjects he concluded that the Balke test gave the best value for the maximal oxygen intake, with the treadmill test, the bicycle ergometer test and the Cureton test giving lower values, respectively. No statistical evaluations are given.

Most investigators who have used the bicycle ergometer to test aerobic capacity have used graded workloads on successive days (5, 10, 63, 70). Recently, Binkhorst and van Leeuwen (15) compared the method of Astrand (5) with successive increments done on the same day and with a steady load that caused a heart rate between 140 and 150 beats per minute done to exhaustion. They obtained no significant differences between the methods and concluded (15:466) "it appeared that aerobic capacity can be determined with the bicycle ergometer by continuously increasing the load in a single session".

Hettinger, et al (45), using 28 subjects, compared the maximal oxygen intake values obtained with the Astrand test (10) and with the Astrand-Ryhming Predicted test (11) and found the predictions (average = 2.62 liters per minute) significantly higher (p = .05) than the actual values (average = 2.38 liters per minute). They reasoned that this was a result, in part, of constructing the nomogram from studies with trained athletes.

Very recently, (March, 1964), de Vries and Klafs (34) reported a study that compared a variety of submaximal predictive tests of maximal oxygen intake with a maximal test on a bicycle ergometer. They used 16 subjects and obtained the actual measurement of maximal oxygen intake using a procedure similar to that of Mitchell, Sproule and Chapman (61) with a warm-up consisting of the Sjöstrand test (76). Six submaximal tests were used to predict actual values for maximal oxygen

intake. They were the Sjöstrand Test, a Modified Sjöstrand Test, the Harvard Step Test, a Progressive Pulse-Ratio Test, the Delta R.Q. Test and the Astrand-Ryhming Predictive Test. The authors found significant correlations (p = .01) between the obtained maximal values and the following submaximal tests: a) Sjöstrand test expressed in kilopond meters per minute per kilogram of body weight (r = .877), b) Harvard Step test expressed in milliliters per kilogram of body weight (r = .766), c) Sjöstrand test expressed in terms of body surface (r = .762) and d) Astrand-Ryhming test expressed in liters per minute (r = .736). Since the Astrand-Ryhming test is shorter and uses only one work load, the authors concluded that no advantage was gained in using the Sjöstrand test. It was also noted that those tests in which heart rate during a measured workload is the basis of prediction seem to have a greater predictive value than those using heart rate in the recovery period.

Factors that Influence Maximal and Submaximal Oxygen Consumption:

Taylor, et al (84) gave a lengthy discussion of such factors as environmental temperature, fatigue, meals, lack of sleep, work efficiency, and the effect of emotion during submaximal work as measured by pulse rates. These factors all appeared to have effects that depend upon the testing conditions. Many of them, however, become greater when maximal levels are reached. Some parameters such as age, body size, sex, training, and various functional capacities influence both maximal and submaximal determinations (84).

Environmental Temperature: Williams, et al (93) reported that a hot environment will move the pulse-rate per work rate curve to the left, increasing the pulse rate for a given submaximal oxygen consumption but that maximum pulse rates were not altered. Rowell, et al (cited in 84) using unacclimatized subjects, reported that in a hot environment maximal pulse rate was reached at a lower workload and that the oxygen intake could increase as much as two liters per minute after this maximal pulse

rate had been reached. Williams, et al (93) attributed this largely to individual adaptation to heat, and suggested that if all such experiments were conducted in an ambient temperature of about 65 degrees Fahrenheit these inter-individual effects would be minimized.

Exercise and Fatigue: In studying only submaximal work levels, Lundgren (57) found that after an 8-hour workday in a lumber camp the pulse rate response to a given amount of exercise increased. He also found that walking 7 kilometers did not affect the pulse-rate per work-rate curve but that walking 15 kilometers did.

Brozek and Taylor (20) reported that fatigue induced by lack of sleep had no effect on the working pulse rate. They used twelve trained subjects who went sleepless for 62 hours.

Food Ingestion: Lundgren (57) reported large increases in pulse rate for a fixed amount of work both before and after breakfast. At an oxygen consumption of one liter per minute, he reported an average increase of 18 beats per minute. Taylor, et al (84) stated that even though we know that pulse rate and cardiac output are affected by food ingestion, not enough information is available to extrapolate to maximal levels.

Effects of Emotion: According to Taylor, et al (84), physiologists who use submaximal tests are basing their work on an assumption that working stress will overcome any emotional effects or behaviour that would normally affect a resting pulse rate. Astrand, et al (9) agreed with this statement and at the same time acknowledged marked emotional influences during a resting state. Brouha and Heath (18) also reported agreement from studies of subjects prior to performance of the Harvard Fitness Test. Taylor and his co-workers (84) threw some doubt into this idea by reporting definite deviations from normal during a low submaximal treadmill walk because of a sudden shock of falling. They also showed, however, that even

during catheterization there was very little pulse variation among trained subjects during both submaximal and maximal work. Any deviations noted were the result of a conditioning program, and appeared only during submaximal work; the maximal pulse rate was unaffected. Taylor, et al also pointed out that care must be taken when using a test with a pulse rate cut-off as a criterion. Stress may cause the pulse to reach the criterion prematurely.

It is of note that most of the data reported about emotion and its effects on the maximal oxygen intake has been a result of intermittent work and much more study is required before any conclusions can be made.

Type of Work and Mechanical Efficiency: There is wide usage of both the treadmill and the bicycle ergometer in submaximal and maximal work testing. The ideal test would be one which all subjects could perform with the same degree of skill. Dill, et al (35), in 1930, reported measureable differences among subjects in the mechanical efficiency of running, and more recently, Erickson, et al (15) has stated that maximal oxygen intake values become stable after the second time on a treadmill and thereafter are not influenced by experience. Knehr, et al (54) also reported small (less than 5%) changes in the oxygen intake with experience in walking on a treadmill. Astrand (7) concluded that learning is negligible on the bicycle ergometer but Krogh and Lindhard (56) reported, in 1920, that areas where bicycle riding is not popular may show substantial changes in mechanical efficiency with practice. Astrand (7) also reported that there is almost no difference in oxygen requirements with change in body weight as measured by the bicycle ergometer.

Body dimensions: It has been recognized for a long time that maximal oxygen intake is a function of body size. Body weight has been systematically related to maximal oxygen intake by Robinson, et al (66, 69) and

Wyndham, et al (94). Statistically significant relationships (p = .05) between body weight and maximal oxygen intake have been shown by Buskirk (21), Buskirk and Taylor (22), Coyne (29), and Welch, et al (92). Buskirk and Taylor (22) also showed a significantly higher correlation with fat-free body weight (0.85) than with body weight (0.65) while Coyne (29) reported much lower values for fat-free body weight (0.39) and body weight (not significant from zero). Coyne also noted (29:81) that a more satisfactory value (0.53) was obtained from a multiple correlation involving fat-free body weight, total body fat, and total body weight. Taylor, et al (84) conceded that fat-free body weight had a higher correlation but claimed that body weight was more practical and was adequate as a reference point to use for setting standards for individual judgment. Craig Taylor (80) reported that in submaximal exercise, oxygen consumption was largely a function of body weight but that during maximal work this relationship dropped markedly.

Blood volume (22) and the total amount of circulating hemoglobin (77) have been used as reference values and von Döbeln (87) has reported a high correlation between these parameters and body weight. It also seems reasonable to expect heart size, blood vessel size and the amount of working muscle mass to be determining factors in an individual's maximal oxygen uptake (84).

Consolazio, et al (28) reported a nomogram for surface area calculated from the Du Bois-Meeh formula (28:27). de Vries and Klafs (34) report a correlation of .762 between the Sjöstrand submaximal test expressed in milliliters per minute per square meter of body surface and maximal oxygen intake expressed in kilograms of body weight.

Age: Inter-individual variations are reduced with a reduction of subjects' age range (6, 66, 69). There is no doubt that increasing age results in a decrease in the aerobic capacity of an individual (after age 20 - 30) (3, 66). Wyndham and Ward (95) postulated that this reduction in aerobic capacity may be a result of decreased pulmonary-arterial diffusion.

Sex: The Astrands (3, 6) reported definite, systematic variations in maximal oxygen uptake of males and females. Brouha and Radford (19) reported that sex quantitatively influenced the cardiovascular reaction to exercise.

Training: Definite increases in maximal oxygen intake have been reported as a result of training or regular exercise. Knehr, et al (54) reported a 7 percent increase among 14 men studied over a period of six months' training. Robinson (67) found a 16 percent increase in maximal oxygen intake with middle distance runners. Buskirk and Taylor (22), Dempsey (33) and Watson (90) found increases in maximal oxygen intake with individuals undergoing regular physical training.

Warm-up: A bout of exercise or "warm-up" is generally agreed to invoke an increase of about five percent in the maximal oxygen intake (84). Use of a warm-up enabled greater reliability upon a retest (61). Asmussen and Bøje (1) stated that subjects "feel" better after undergoing a warm-up. It is evident that investigators favour some sort of warm-up because all commonly used tests of maximal oxygen intake employ a warm-up procedure.

Cardiac Output: Traditional thinking has been to relate increase in oxygen uptake primarily to cardiac output but recent work (61) has emphasized the integration of many more cardiovascular factors. These authors demonstrated that the A-V oxygen difference was the major factor that allowed great increases in blood carrying capacity. They did not, however, negate the importance of increased cardiac capacity during exercise. Williams, et al (93) reported that when maximal oxygen intake was reached, temperature regulation became subservient to supplying the muscle with blood. Taylor, et al (84) added that this results in a marked vasoconstriction of the vascular beds outside the heart, brain, lungs and muscle. This appeared to be the explanation of why maximal oxygen intake was less susceptible

to the outside influences that make submaximal interpretations so difficult (84).

Pulmonary Function: It has been expressed, by Wyndham and Ward (95), that pulmonary factors do not limit aerobic capacity. Mitchell, Sproule and Chapman (61) gave as a reason for this the fact that arterial oxygen tension is maintained throughout heavy exercise.

It is clear that maximal oxygen intake is considerably more stable than submaximal work pulse rates. This enables an investigator who chooses maximal oxygen intake tests in preference to submaximal tests, to relax much of the rigid standardization so necessary with pulse orientated submaximal testing procedures (84).

Testing Maximal Oxygen Intake: Although conditions need not be controlled as rigidly as those of submaximal tests, definite and necessary standards must be adhered to if any conclusions are to have meaning. It is unanimously agreed upon that: a) the intensity and duration of exercise cannot exceed the capacities of the poorest subject, and b) the test must also bring the subjects to a comparable degree of exhaustion. To control these factors, authors have set up definite criterion levels (6, 14, 61, 82) which will be explained in Chapter III. Two types of maximal tests have been developed to attain this standard. They are:

1. Use of a single work load, set initially near to the subject's capacity, that is continued until exhaustion or fatigue (10, 13, 51, 54, 63), and

2. Use of a graded series of work loads that gradually bring the subject to the point of exhaustion (6, 12, 63, 82).

It should be noted that Taylor (79) pointed out a marked positive skewness in the distribution of values obtained from a single load test. He also showed that an approximately normal distribution of values occurs

with a heterogenious group on graded series tests.

The most common media used for testing are the motor driven treadmill, the bicycle ergometer, and the stepping bench. The stepping bench will not be dealt with in this paper.

These testing devices have been developed to conform to the following guiding principles used in setting up maximal oxygen intake or working capacity tests (12, 70, 82, 88):

(a) a large number of muscle groups should be involved to alleviate exercise stoppage from local muscle fatigue and to insure maximal taxing of the cardiovascular system.

(b) sufficient workloads must be used to be able to estimate a subject's maximum performance level.

(c) a steady state performance level must be possible for all subjects during moderate workloads.

(d) the duration of the test must not be excessive.

Definite preference exists among the current investigators in the use of the treadmill or bicycle ergometer. Erickson, et al (37) and all who prefer the treadmill, do so on the following grounds: (a) work load on a treadmill is fixed, (b) skill is not involved because everyone knows how to walk and run, (c) more muscle groups are used and thus a larger energy expenditure is possible, and (d) work load is automatically adjusted to body size. Proponents of the bicycle ergometer say: (a) it is practical, comparatively inexpensive, portable and easy to handle, (b) workloads can be reproduced as exactly as those on the treadmill, (c) mechanical efficiency varies little among individuals, and (d) blood samples and gas analysis are more readily performed with a bicycle (5, 59, 77).

Tests Used in the Assessment of Aerobic Capacity: Three of the commonly used tests of aerobic capacity are:

1. The Taylor, Buskirk and Henschel Treadmill Test of Maximal Oxygen Consumption (82).
2. The Mitchell, Sproule and Chapman Maximal Oxygen Intake Test (61), and
3. The Astrand Bicycle Ergometer Test of Maximal Oxygen Uptake (5).

These tests will be explained in detail in Chapter III. The Taylor, Buskirk and Henschel test is reported to be reliable (r = 0.95), and a one-year retest correlation of 0.98 (22:75) was also reported. The two treadmill tests are very similar, the Mitchell, Sproule and Chapman test being a one session modification of the Taylor, Buskirk and Henschel test, which can take up to five sessions. Both tests are based on graded workloads with rests between each load. They employ a constant speed with the workload being increased by increasing the slope of the treadmill.

The Astrand Bicycle test is based on a similar principle of alternate work and rest periods. Each workload, as performed, is set by increasing the resistance that the subject must pedal against. It makes use of an efficiently designed bicycle ergometer developed and refined in 1954 by von Döbeln (85).

Each of these tests makes use of a definite end point or criterion to determine when a subject has attained a maximal oxygen intake. Associated with each workload increase is an average increase in oxygen uptake and the criterion values are assigned proportions of these increases. The criterions are: Mitchell, Sproule and Chapman, 53 ml. per minute (61:539), Taylor, Buskirk and Henschel, 149 ml. per minute (82:76) and Astrand (3), 80 ml. per minute. If a subject obtained a value that decreased or did not increase a greater amount than the criterion, then he was said to have reached his maximal oxygen intake. Wyndham, et al (94) have expressed disagreement with this method of determining the end point because maximal

oxygen intake is asymptotically approached. They postulated that many of the values obtained using these criterion are underestimations of the true maximal values.

Prediction of Maximal Oxygen Intake from Submaximal Work: Even though reliable methods for direct measurement of maximal oxygen intake exist, they are usually not suitable for testing a large group in a reasonable length of time. To enable a testing program to be done, some investigators have made use of the close linear relationship between pulse rate and oxygen consumption during controlled, stressful, submaximal work (31, 37, 45, 57, 79, 88). Correlations of 0.972 (Erickson, et al (37)) and 0.969 (Taylor (79)) have been reported between heart rate and work load.

Sjöstrand (76), de Vries and Klafs (34), von Döbeln (87), and Astrand (5, 14, 32) have used this relationship to predict a subject's maximal oxygen intake. With definite precautions and provisions (7), useful approximations can be made of an individual's aerobic capacity by means of extensive empirical analysis of actual relationships. Astrand and Ryhming (11), constructed a nomogram from such an analysis that has been widely used since 1954 (17, 34, 86). It involves prediction of a subject's maximal oxygen intake value from a pulse rate that is elicited by a controlled and steady submaximal workload. This known workload is designed to result in a steady state pulse rate between 125 and 170 beats per minute. Standard adjustments are made for age (3), sex (6) and apparatus used for the exercise (11).

Values obtained with this nomogram have been tested for accuracy by Astrand (3) and Hettinger (45). The latter found a significantly higher mean ($p = .05$) obtained on the predicted test than on the Astrand Bicycle Ergometer test (5).

Astrand (3:59), in an attempt to clarify use of the nomogram, states

firmly that:

> This method of measuring only the submaximal oxygen uptake or workload and heart rate will always be only an aid for a rough prediction of the aerobic work capacity. If one wishes to obtain more exact information, it is necessary to measure the aerobic capacity directly.

CHAPTER III

METHODS AND PROCEDURES

Forty-eight healthy male subjects were used in this study with the total being comprised of volunteer students and staff members of the University of Alberta as well as soldiers of the Princess Patricia Canadian Light Infantry stationed at Griesbach Barracks, Edmonton, Alberta. The ages of the subjects ranged from 17 to 35 with the mean age being 23.

The tests were conducted over a period of two to three weeks for each subject with a minimum of two and a maximum of seven days between separate tests.

In order to reduce the possible training effect of the series of tests on the obtained mean values of the maximal oxygen intake of the different tests, the testing order was arranged by means of permutations. The permutations of testing sequences were drawn up prior to the commencement of the experimentation, and each permutation was given a number. Subjects and numbers were matched by a chance procedure. The following formula was used to determine the permutation number:

${}^{n}P_{r}$ = number of arrangements of three tests taken three at a time

$$= N\,(n-1)\ldots(N-r+1) = \frac{N!}{(N-r)!}$$

Where $N = r = 3$

$${}^{n}P_{r} = 3! = 6$$

<u>Physical Conditions of the Testing Situation</u>: As has been noted in the previous chapter, the maximal oxygen intake can be affected by temperature variation (72, 82) in the testing situation. In this study the laboratory temperature was standardized at 72 ± 4 degrees Fahrenheit but the relative humidity was not controlled.

<u>Standardization of the Test Situation</u>: In view of the known effect of the ingestion of food on pulse rate and cardiac output (59, 82) no test was

scheduled for a period of one and a half hours following a meal. Subjects were requested not to smoke prior to the test and although Lundgren (59) indicated that moderate amounts of work prior to a test did not affect the maximal oxygen intake, all subjects were advised not to perform any abnormal or strenuous activities for two hours before their appointment. In all instances, the test schedules for each individual were arranged so that the subject was tested at the same relative time of the day.

Orientation Period: Every subject was brought to the laboratory one to three days prior to the commencement of the actual test for the purpose of orientation. At this time height, weight, age, and smoking habits were recorded. The testing procedure was explained as carefully as possible and each subject was given a copy of his testing timetable. Since most of the subjects were unfamiliar with the motor driven treadmill and the bicycle ergometer, they were given ample opportunity to practice on both instruments (37, 54). The subjects were also familiarized with the respiratory apparatus. Following this practice period the subject was permitted a thirty minute rest and this was followed by an exhaustion run on the treadmill conducted in the manner described by Johnson, Brouha and Darling (51).

Respiratory Apparatus: A Modified Otis-McKerrow two-way respiration valve of low resistance diaphragm type, shown in Figure V, was used in this study. The valve was connected by a 1.5 inch flexible plastic hose to a 200 liter Douglas bag. A three-way Thomas valve was placed at the junction of the airway leading from the mouthpiece into the Douglas bag. Figure IV shows how the valve, mouthpiece, and connecting tubes were supported by a headgear comfortably fitted to each subject.

Pulse Rate Recordings: Heart rate recordings were made by means of the Sanborn 100 Viso-Electrocardiograph shown in Figure III. Figure IV reveals the placement of two chest electrodes and a reference electrode fitted to

the subject's forehead. Careful attention was given to preparation of the electrodes with Redux paste (tradename) to ensure better recordings.

Surface Area: The body weight and height of each subject were applied to the Du Bois-Meeh formula (Consolazio 28:27) to obtain values for surface area.

Johnson, Brouha and Darling Test of Physical Fitness for Strenuous Exercise (Harvard Physical Fitness Test) (51). This test was used by Taylor, et al (82) to make an estimation of the correct grade which would yield a maximal oxygen intake. The test was performed on a Motor Driven Treadmill with a speed range of 0-15 miles per hour. Each subject was told exactly what procedures would be followed. These are listed below:

1. The subject warmed up by walking at an 8.6 per cent grade for five minutes at 3.5 miles per hour.
2. A rest period of five minutes in the sitting position was allowed.
3. At a signal, the subject began to run uphill at 7 miles per hour on a grade of 8.6 per cent. If he was not exhausted at the end of the five minutes he was stopped. In all cases, the duration of the run was noted to the nearest second.
4. Recovery time was noted from the cessation of the run and pulse rates were recorded on the electrocardiogram from 1 to 1.5, 2 to 2.5, and 4 to 4.5 minutes of recovery.
5. An arbitrary score of physical fitness was calculated by the formula:

$$\frac{\text{(Seconds the subject ran) X 100}}{\text{2 X sum of three half-minute recovery pulse rates}}$$

This test was done in conjunction with a related study that included the Taylor, Buskirk and Henschel Maximal Oxygen Consumption Test (82).

Mitchell, Sproule and Chapman Maximal Oxygen Intake Test (61). This maximal oxygen intake test has been described by Mitchell, Sproule and Chap-

man (61) and, with some modifications, by Cunningham (32), Coyne (29) and Watson (90). However, these modifications have not been included in this experiment. The test was performed on a motor driven treadmill. The following procedures were carefully adhered to:

1. A 10 minute warm-up walk was performed at 3 miles per hour on a 10 per cent grade. This warm-up was followed by a 10 minute rest in the sitting position.
2. Before the treadmill was started, the subject was connected to a two-way Otis-McKerrow valve by means of a rubber mouthpiece, and his nose was completely closed with a nasal clamp.
3. The exercise runs were carried out at a speed of 6.0 miles per hour for 2.5 minutes and expired air was collected in a Douglas bag between 1 minute and 30 seconds and 2 minutes and 30 seconds of the run.
4. Analysis of the expired air was immediately carried out.
5. After a 10 minute rest period, the work load was increased by raising the grade to 2.5 per cent, the speed being held at 6 miles per hour, and the procedure was repeated until the oxygen intake, measured in liters per minute, levelled off or declined. The criterion for deciding whether or not maximal oxygen intake had been reached has been determined by Mitchell, <u>et al</u> (61:539) to be a decline in value or an increase of less than 0.054 liters of oxygen per minute between two successive tests.
6. The subject was requested to do the succeeding work level in order to determine any further changes in the oxygen intake values following the establishment of the maximal oxygen intake according to the criterion established by Mitchell, <u>et al</u> (61).

Astrand Bicycle Ergometer Test of Maximal Oxygen Uptake (Modified). The bicycle ergometer test was carried out on a Monark Bicycle Ergometer which was designed by von Döbeln (85) and which works on the principle of a weighing device called the sinus balance. Figure VIII shows the bicycle used and Figure IX reveals a close view of the sinus balance during calibration. The procedures adopted were closely patterned after those used and established by Astrand (4, 5, 6, 7, 10). The only modification to the test was to have the subjects perform the test in a single experimental period until the maximal oxygen intake criterion was reached.

The pedalling frequency was established by means of an electric metronome (with attached visual stimulator) which was set at exactly 100 single beats per minute. The metronome timing was followed so that 50 complete pedal turns per minute were made. The sinus balance was carefully zeroed before the commencement of the test.

When the work was started, the brake belt was slack and was quickly adjusted to the desired work level by stretching the belt with the aid of a handwheel designed for the purpose. This adjustment could be made in a few seconds but as the wheel and belt warmed up the friction sometimes changed, necessitating the occasional readjustment. A check of the load was made at least once a minute.

The height of the saddle was adjusted so that when the subject had the front part of the sole of his foot level on the pedal, a slight bend of the knee joint resulted in the extended leg (i.e., the front part of the knee was straight above the tip of the toes). The handlebars were adjusted to the subject's liking.

The same equipment used to obtain heart rate and expired gas samples in the treadmill tests was utilized in this test.

Procedure:

1. The subject was allowed to warm-up for six minutes at the 600 kpm work level which was followed by a five minute rest interval.
2. The work load was increased to 900 kpm and the subject again pedalled at a frequency of 50 revolutions per minute for six minutes. At 3 minutes and 30 seconds of the ride the subject was connected to an Otis-McKerrow two-way breathing valve by means of a rubber mouth piece and his nose was completely closed with a nasal clamp. Two expired gas samples were obtained, one between the fourth and fifth minute and a second between the fifth and sixth minute. The mean values of oxygen consumption were used unless the second bag showed a significantly higher value (10). A difference of greater than 80 milliliters was considered to be a significant difference (3).
3. A second 5 minute rest period ensued and this was followed by 6 minutes of work at the 1200 kpm level. The above procedure was repeated through the 1500, 1800, 1950 kpm levels or portions thereof or until the oxygen intake levelled off or declined. The criterion for deciding whether or not the maximal oxygen intake had been reached was given by Astrand (3:49) to be a decline in value or an increase between two successive recordings on separate work levels of less than 0.081 liters of oxygen per minute.
4. The subject was then requested to attempt the next work load in order to ascertain changes that might occur in the oxygen uptake values following the establishment of the maximal oxygen uptake according to Astrand's criterion.

Modified Astrand-Ryhming Nomogram for the Prediction of Maximal Oxygen Uptake from Submaximal Work (3, 11). For all subjects in this study, the work level was initially set at 900 kpm. Saddle and handle-bar height were

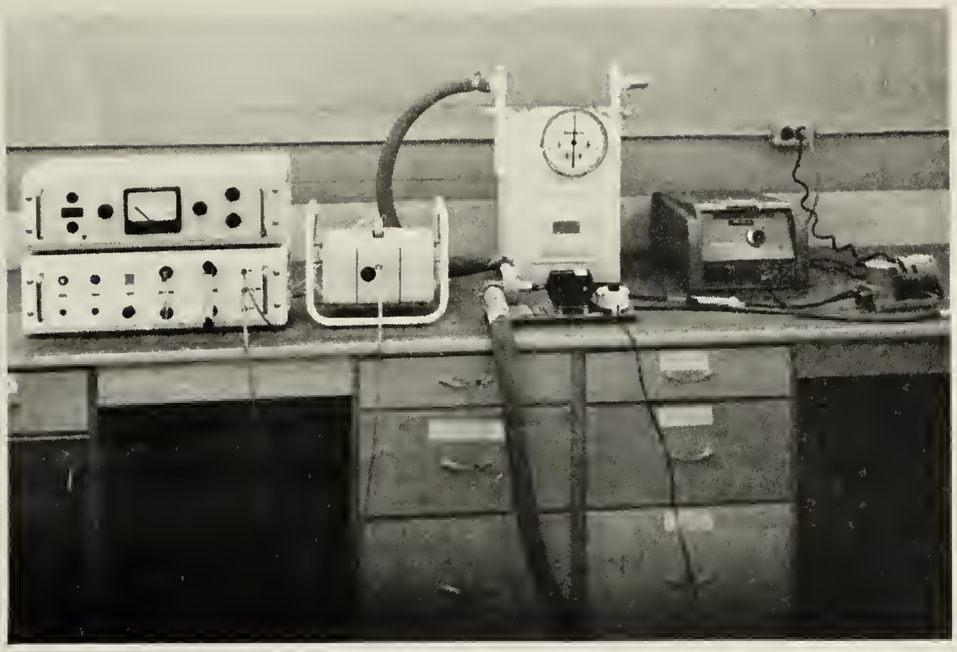


FIGURE I. (left to right).
N.V. Godart CO_2 Analyzer,
Volume meter, Beckman E-2
O_2 Analyzer

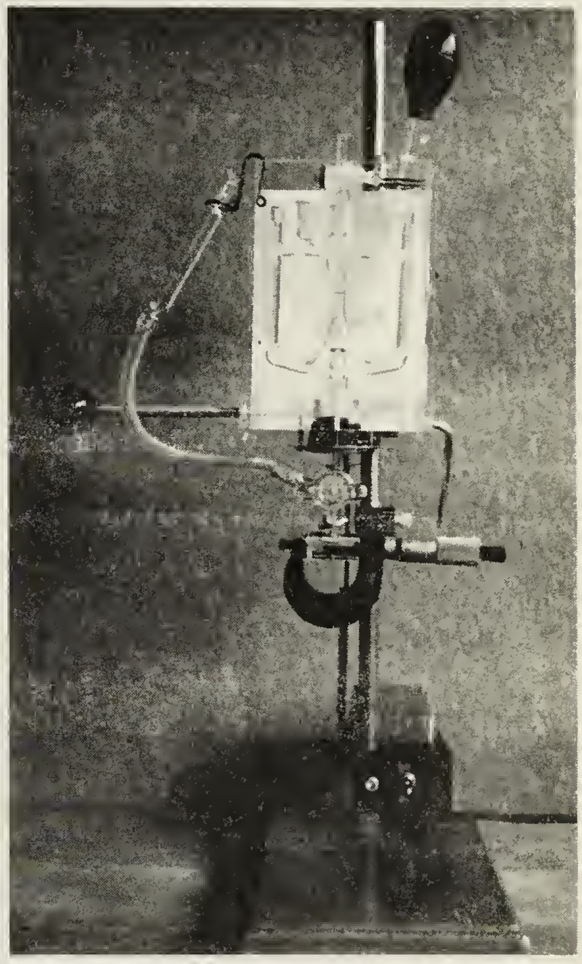


FIGURE II. Micro-Scholander Gas Analysis Instrument

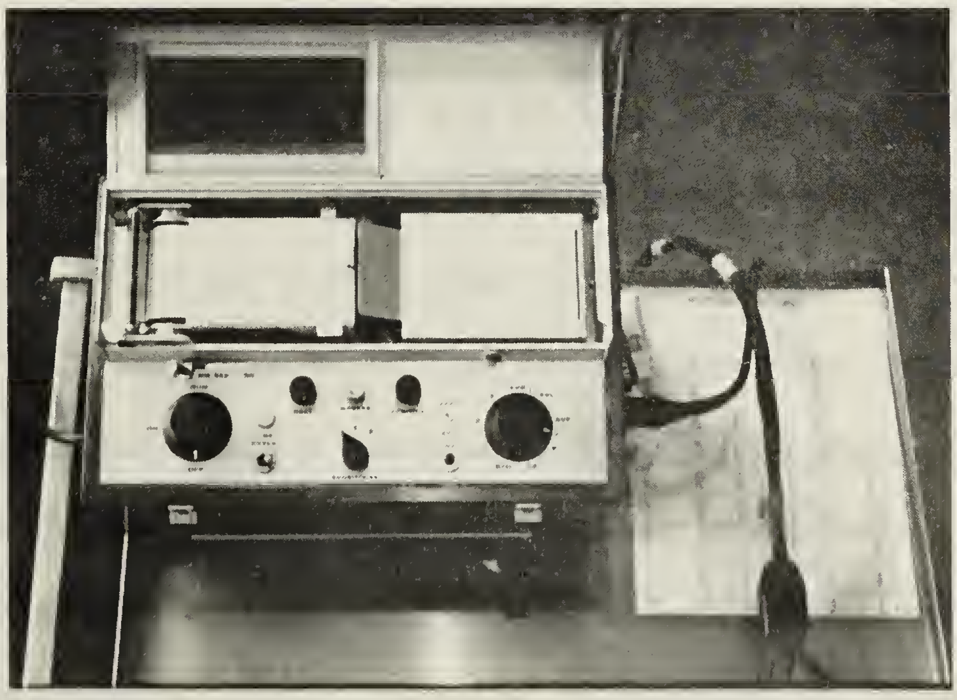


FIGURE III. Sanborn 100 Viso-Electrocardiogram

adjusted as per previous description and the pedal frequency established at 50 revolutions per minute. Heart rate recordings were made on a Sanborn 100 Viso-electrocardiograph during the last five seconds of every minute. The subject pedalled at this work level until a steady state was attained. If, after six minutes this steady state was not in the range of 125 to 170 beats per minute, the work load was increased to 1200 kpm and the subject continued to ride until a steady pulse rate was reached.

The steady state pulse rate value was then applied to the Astrand-Ryhming nomogram (11) as adjusted for age (3) in relation to the work load and a maximal oxygen uptake value was estimated.

Figure VII demonstrates the performance of a subject doing the sub-maximal test.

Method of Determining Oxygen Consumption. The expired air in the Douglas bag was analysed for the percentage of oxygen by drawing a sample of expired air through the exit tubing of the bag via a $\frac{1}{4}$" vinyl hose into a Beckman #E-2 oxygen analyser. The percentage of carbon dioxide was determined by the same procedure, using a #KK Godart Capnograph infra-red carbon dioxide analyser. Both gas analysers, shown in Figure I, were carefully calibrated prior to use each day and at regular intervals during the testing procedure. The volume of expired air was determined by passing the contents of the bag via a 1.5 inch rubber hose leading from the three-way Thomas valve through a #802 American Meter Company Gasometer at a constant rate of 70 liters per minute with a Collins #p-553, 1/15 horse power centrifugal pump shown in Figure I. The total volume was corrected to standard temperature and pressure dry from a table of factors calculated with the formula given by Consolazio (28:6). For the calculation of oxygen consumption, the change in nitrogen content for correction of expired to inspired volumes, as described by Peters and Van Slyke (65), was employed. The method of

FIGURE IV. (left to right)
Douglas Bags
Breathing Apparatus
Treadmill
Instrument Panel

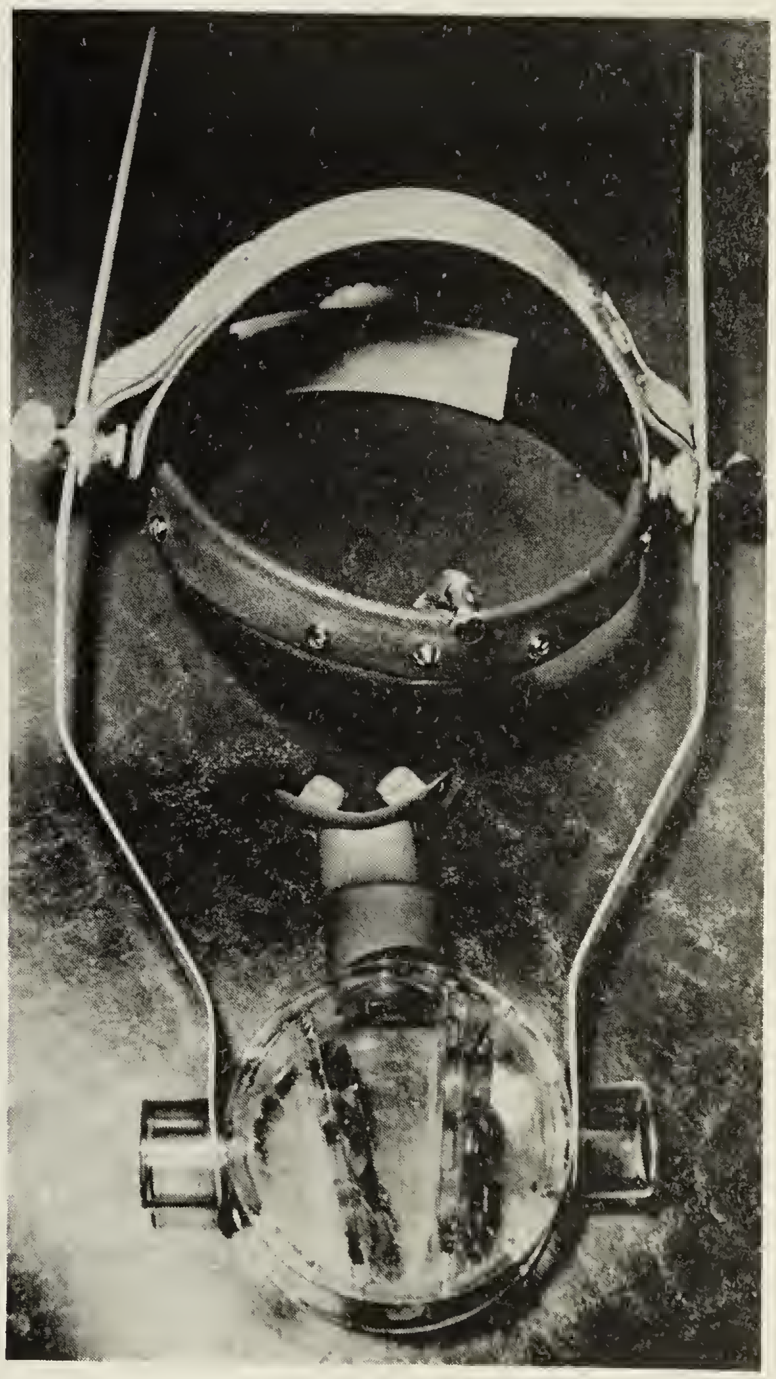


FIGURE V. Modified Otis
McKerrow Valve with
light weight head gear.

FIGURE VI. (left to right)
Sanborn 100 Viso-Electrocardiogram
Subject showing ECG electrode placement
Electric Metronome

calculation is shown below:

1. The following symbols are used for this study:

   a) Fe = % of a particular gas in expired air.

   b) Fi = % of a particular gas in inspired air.

   c) Ve = Volume expired.

   d) Vi = Volume inspired.

   e) ATPS = Atmospheric temperature, pressure, saturated.

   f) STPD = Standard temperature, pressure, saturated.

2. The corrected volume of air expired is:

   Ve air STPD = Ve ATPS X the factor for reducing a volume of moist gas to a volume of dry gas at 0° C. and 760 m.m. of mercury.

3. The corrected per cent of oxygen in the expired air is:

   $$\text{Fe } O_2 = \text{Analyser reading} \times \frac{2.5}{1000}$$

4. The volume of inspired air is:

   $$\text{Vi air STPD} = \text{Ve air STPD} \times \frac{\text{Fe } N_2}{\text{Fi } N_2} \quad (\text{Fi } N_2 = 79.03)$$

5. The total volume of oxygen inspired (not all consumed) is:

   $$\text{Vi } O_2 = \text{Vi air} \times \frac{\text{Fi } O_2}{100} \quad (\text{Fi } O_2 = 20.94)$$

6. The volume of oxygen expired (not consumed) is:

   $$\text{Ve } O_2 = \frac{\text{Fe } O_2}{100} \times \text{Ve air}$$

7. The amount of oxygen consumed is:

   $$VO_2 = \text{Vi } O_2 - \text{Ve } O_2$$

<u>Calibration of Instruments and Accuracy of Calibration Gases</u>

<u>Treadmill</u>. The elevations of the treadmills used in this experiment were carefully checked by means of a Miracle Point Mercury Balance Model 10 Inclinometer which registered in degrees. The values were converted to a per cent scale by using a table of tangents (23).

FIGURE VII. Subject undergoing Astrand-Ryhming Nomogram Test

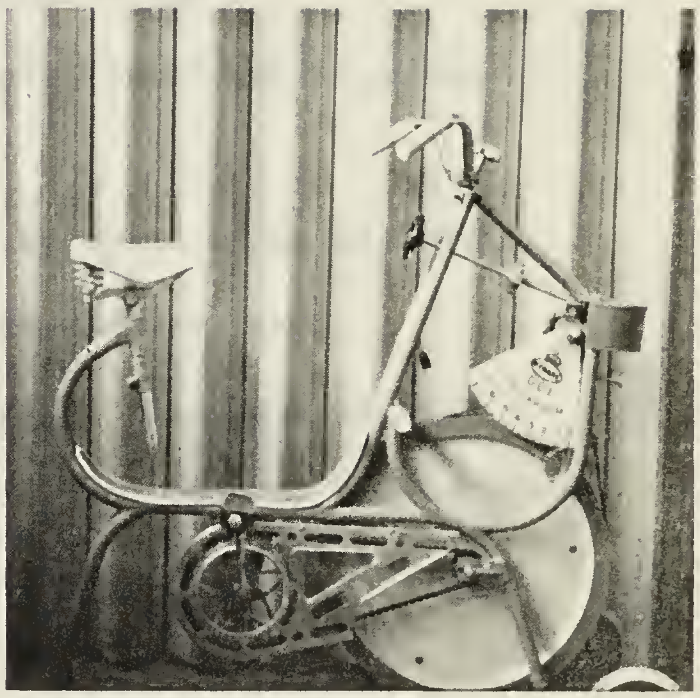


FIGURE VIII. Monark GCI Bycycle Ergometer

FIGURE IX. Calibration technique for Monark Bicycle Ergometer using 3 kilogram weight.

Bicycle Ergometer. The sinus balance was calibrated by means of a set of stainless steel weights, #750 Class S-1 Serial No. 7Y1458 (see Figure IX) in the following manner (8:3):

a) The brake drum was removed and the mark on the pendulum weight was set at "0".

b) A one kilogram weight was attached to the spring as shown in Figure IX. Weights were added or taken from the spring as required to bring the mark on the pendulum to the required scale mark of "1-kp".

c) The process was continued through "2-kp", "3-kp" and so on up to "7-kp".

d) If adjustment was required it was made by means of an adjusting screw which altered the center of gravity of the sinus balance.

American Volume Meter and Collins Centrifugal Pump. The rate of flow through the #802 American Meter Company Gasometer was checked by evacuating a known quantity of gas from a Collins Chain-Compensated Gasometer with a capacity of 120 liters and a factor of 133.2 cc/min.

Calibration Gases for the Beckman E-2 Oxygen Analyzer and Godart Capnograph Carbondioxide Analyzer.

The calibration gases used for calibrating the two instruments were evaluated several times by means of an analytical procedure outlined by Scholander (74) (see Figure II). The tests were carried out by the laboratory technician in the Department of Physiology and the Cardio-Pulmonary laboratory of the University of Alberta hospital.

Statistical Procedures.

1. The Pearson Product-moment correlation coefficient (41:92) was used to determine the relationships between subjects and tests for all values obtained. These were also carried out with the measured parameters of height and weight and the calculated values for surface area. Calculations

were performed by an IBM-1620 Electronic Computer using a program of simple correlations (#1620-013) which also provided a mean, standard deviation, and variance for each variable. A t-test was run for significance of the difference between correlations (78:253). A two-way analysis of variance was determined using the means obtained from the three maximal oxygen tests. Duncan's New Multiple-Range test was used to determine if differences between means had occurred.

CHAPTER IV

RESULTS AND DISCUSSION

Results

Means, Standard Deviations and Range Values for Height, Weight and Surface Area: Table I gives the means, standard deviations and range values for the forty-eight subjects used in the study.

TABLE I

DATA FOR HEIGHT, WEIGHT AND SURFACE AREA

Parameter	Mean	Standard Deviation	Range
Height (inches)	70.1	2.4	67.0 - 78.0
Weight (kilograms)	75.46	8.71	53.98 - 96.39
Surface Area* (square meters)	1.927	0.126	1.588 - 2.214

* Consolazio (28:27), calculated from the Du Bois-Meeh formula.

Means, Variances and Standard Deviations for the Maximal Oxygen Consumption Tests: The means, standard deviations and variances for maximal oxygen consumption obtained on the three tests used in this study are given in Table II.

TABLE II

MEAN MAXIMAL OXYGEN CONSUMPTION VALUES

Test	Maximal Oxygen Consumption					
	liters/min.			ml./kg./min.		
	Mean	S.D.	Variance	Mean	S.D.	Variance
Mitchell, Sproule and Chapman	3.674	.513	.263	48.90	6.52	42.52
Astrand Bicycle Ergometer	3.425	.459	.210	45.62	5.58	31.16
Astrand-Ryhming Nomogram	3.664	.782	.611	48.60	9.06	82.15

S.D. = Standard Deviation

The mean score (Fitness Index) for the forty-eight subjects on the Johnson, Brouha and Darling Test of Physical Fitness was 65.05 ± 19.44 and the mean time for the twenty-five subjects who did not complete the run (endurance time < 300 seconds) was 199.26 ± 50.95 seconds.

Correlation Coefficients: The relationships between the values obtained on the maximal oxygen intake tests, the values obtained on the Johnson, Brouha and Darling test and the determined parameters of the forty-eight subjects were obtained using a program of simple correlations developed for an International Business Machine Model 1620 computer. The correlations were determined using both milliliters of oxygen consumed per kilogram of body weight per minute and in liters of oxygen consumed per minute for each of the oxygen consumption tests. The Pearson Product-moment correlation coefficient was the basis of the program used. Table III contains the results of the computer analysis.

TABLE III

CORRELATION COEFFICIENTS OBTAINED BETWEEN THREE MAXIMAL OXYGEN CONSUMPTION TESTS AND JOHNSON, BROUHA AND DARLING FITNESS SCORES AND ENDURANCE TIMES, HEIGHTS, WEIGHTS AND SURFACE AREAS
(N = 48)

Test		JBD		Height	Weight	Surface Area
		FI	TR (N=25)			
Mitchell, Sproule	liters/min.	.38**	.26	.34*	.50**	.48**
and Chapman	ml./kg./min.	.46**	.45*	-.19	-.34*	-.31*
Astrand Bicycle	liters/min.	.46**	.38	.39**	.49**	.50**
Ergometer	ml./kg./min.	.55**	.42*	-.13	-.36*	-.29*
Astrand-Ryhming	liters/min.	.55**	.13	.33*	.49**	.48**
Nomogram	ml./kg./min.	.69**	.28	.01	-.04	-.02

JBD - Johnson, Brouha and Darling Physical Fitness Test.
FI - Fitness Index
TR - Time Run (endurance)
** - Statistically significant at the .01 level
* - Statistically significant at the .05 level

It should be noted that the correlations in Table III have all been cal-

culated on the basis of forty-eight subjects except in the case of time run (endurance) on the Johnson, Brouha and Darling Test. Twenty-three of the subjects completed the run and necessarily had to be depleted from that comparison in order to conform to the requirements of the Pearson Product-moment correlation determinations (39:86). With this smaller number of subjects (N = 25) a greater correlation was necessary for significance.

The relationships between the three tests of maximal oxygen intake are given in Table IV in terms of both liters per minute and milliliters per kilogram of body weight.

TABLE IV

CORRELATION COEFFICIENTS OBTAINED
BETWEEN THE THREE MAXIMAL OXYGEN CONSUMPTION TESTS

		Astrand Bicycle Ergometer		Astrand-Ryhming Nomogram	
		liters/min.	ml./kg./min.	liters/min.	ml./kg./min.
Mitchell, Sproule and Chapman	liters/min.	.51		.67	
	ml./kg./min.		.39		.53
Astrand Bicycle Ergometer	liters/min.			.62	
	ml./kg./min.				.47

All correlations were found to be significantly greater than zero at the .01 level of confidence (for forty-eight subjects r = .372 indicated such significance).

The design of the three tests of maximal oxygen intake differed widely. Two of the tests required elaborate and extensive equipment to determine a value, as defined for each test, for an individual's maximal oxygen uptake, while the third test was a simple and short predictive test. It was therefore of importance to determine whether any significant relationships occurred between the predicted and actual values of maximal oxygen consumption. Similarly it was of interest to see if one or more of the tests of maximal oxygen uptake correlated better than the others with the physical fitness score.

To test these relationships a t-test described in Walker and Lev (89:256) using the hypothesis that $\rho_1 = \rho_2$ was utilized.

The fitness index was found to correlate significantly better with the Astrand-Ryhming Nomogram (r = .69) than with the Mitchell, Sproule and Chapman test (r = .46) when the oxygen consumption tests were expressed in terms of milliliters per kilogram of body weight (p = .01). No other significant differences were found when the correlations were tested (p = .01).

Analysis of Variance of Maximal Oxygen Consumption Values: In order to test the means of the three tests of maximal oxygen consumption a two-way analysis of variance was used. The test was designed to test the significance of the difference between means from correlated samples (41:291). A summary of the results of the variance analysis for data expressed in liters per minute appears in Table V and results of the variance analysis in terms of milliliters per kilogram of body weight per minute appear in Table VI.

TABLE V

ANALYSIS OF VARIANCE FOR THE THREE TESTS
OF MAXIMAL OXYGEN CONSUMPTION
(Liters of oxygen consumed per minute)

Source of Variation	Sum of Squares	df	Mean Square	F
Between Tests	1.897	2	.949	6.04**
Between Subjects	36.175	47	.770	4.90**
Interaction	14.802	94	.156	
Total	52.874	143		

** Statistically significant at the .01 level.

TABLE VI

ANALYSIS OF VARIANCE FOR THE THREE TESTS
OF MAXIMAL OXYGEN CONSUMPTION
(Milliliters of oxygen consumed per kilogram of body weight per minute)

Source of Variation	Sum of Squares	df	Mean Square	F
Between Tests	315.86	2	157.93	5.50**
Between Subjects	4625.15	47	98.41	3.43**
Interaction	2699.35	94	28.72	
Total	7640.36	143		

** Statistically significant at the .01 level.

Both the raw score means (liters per minute) and the means expressed in milliliters per kilogram of body weight are shown to be statistically different at the .01 level of confidence using the F-ratio test. This means that the null hypothesis with respect to tests does not hold true and must, therefore, be rejected. The F-ratio test, indeed, supports the alternative hypothesis that a real difference does exist between the three means.

The F-ratio test also shows highly significant differences between subjects, as can normally be expected. Some subjects obtained values that were consistently better than others on all trials.

Now that a real difference has been shown to occur between means, it must be determined where this significance lies. Duncan's New Multiple-Range test (78:107) indicated highly significant differences ($p = .01$) between the mean obtained from scores on the Astrand Bicycle Ergometer and the means from each of the other two tests. No statistical differences occurred between any other means. The results of these analyses are given in Tables VII and VIII.

TABLE VII

DUNCAN'S NEW MULTIPLE-RANGE TEST APPLIED TO THE DIFFERENCES BETWEEN K = 3 TREATMENT MEANS EXPRESSED IN LITERS PER MINUTE

Means	3.425	3.664	3.674	Least Significant R
3.425	-	.239**	.249**	R = .221
3.664		-	.010	R = .212

** Statistically significant at the .01 level.

TABLE VIII

DUNCAN'S NEW MULTIPLE-RANGE TEST APPLIED TO THE DIFFERENCES BETWEEN K = 3 TREATMENT MEANS EXPRESSED IN MILLILITERS PER KILOGRAM OF BODY WEIGHT PER MINUTE

Means	45.62	48.60	48.90	Least Significant R
45.62	-	2.98**	3.28**	R = 2.98
48.60		-	.30	R = 2.87

** Statistically significant at the .01 level.

Homogeneity of Variance: A necessary assumption of the analysis of variance is homogeneity of variance. A t-test for homoscedasticity of correlated samples (Ferguson:143) was applied and the modified Astrand-Ryhming test was found to have a significantly greater variance (p = .01) than each of the maximal tests. No difference was found between the maximal tests. A graphic representation of the spread of the score distributions on the three tests is given in Figure X, page 40.

Discussion:

Because of the increasing importance placed on maximal oxygen consumption by physiologists, medical doctors and physical educators as an objective measure of physical fitness (61, 63) it was the purpose of this study to evaluate an inexpensive predictive test of aerobic capacity in terms of two actual tests performed on a treadmill and a bicycle ergometer.

The mean values obtained from the tests executed in this study agree

in character with values cited in the literature. Buskirk and Taylor reported a value of 3.44 ± 0.46 liters per minute for a group of sedentary students and soldiers, aged 18 to 29 (22:72), and Mitchell, et al (61:541) reported a value of 3.37 ± 0.51 liters per minute for a similar group. More recently, Hettinger reported values of 2.38 liters per minute on the Astrand Bicycle test and 2.62 liters per minute on the Astrand-Ryhming predictive test (45:154) as performed by 28 Philadelphia policemen, aged 20 to 30 years. The corresponding values obtained in the present study were 3.67 ± 0.51 on the Mitchell, et al test, 3.66 ± 0.78 on the modified Astrand-Ryhming predictive test and 3.43 ± 0.46 on the modified Astrand Bicycle test. These means were obtained from a group of physically active males, aged 17 to 35 and should be expected to be slightly greater in value. The means given for highly trained subjects are greater still. Astrand reported 4.15 ± 0.36 for 33 Swedish athletes aged 20 - 29 (5), Buskirk and Taylor (22:72) gave a value of 3.95 ± 0.43 for young trained subjects, and Slonin, et al (cited in 61:542) indicated a mean of 4.05 ± 0.39 liters per minute for 65 young trained men. These higher values were probably a result of a greater degree of cardiovascular fitness of the subjects.

A significantly lower mean value of maximal oxygen consumption was obtained from the direct Astrand test when compared to the other tests in this study. Astrand and Saltin (12) agreed with the conclusion of Taylor, et al (82) that individual performance on maximal oxygen consumption tests was dependent upon the nature of the physical activity as well as the muscle mass involved. They stated that running uphill produced a five percent greater maximal value ($p = .05$) than cycling (12). Muscle fatigue must also be considered a factor. Subjects almost always reported that termination of the Astrand Bicycle test was a result of local muscular fatigue (quadriceps) and not total body fatigue. Perhaps the local oxygen supply could not be

utilized by the muscle itself even though excess oxygen was available from the cardiovascular system. Rodahl (71) refers to this as the inability of a subject to load the circulation fully because of muscular insufficiency.

Of prime interest is the fact that the Astrand-Ryhming predictive test differed significantly from the Astrand test (p = .01) and yet was not different from the Mitchell, et al test. Since both bicycle tests were completed on the same ergometer, one would expect a better relationship between them. Hettinger, et al (45) in their study of American policemen, reported similar relationships between the same two tests (p = .05). The results of Astrand-Ryhming's study do not agree. Recall that their nomogram was constructed from the performance of well trained athletes who were probably accustomed to cycling and could exert themselves to a great cardiovascular limit on the bicycle. The subjects in this and Hettinger's study were in all probability, not bicycle oriented and as a result could have terminated their efforts because of local muscle fatigue and/or lack of psychological drive (71). Rodahl also reports that further analysis of three groups of untrained subjects, with special attention paid to maximum effort by the use of blood lactate measurements, produced differences between the two tests of about 1, 3, and 4.8 percent, of which none were significant (71:254). This would suggest that the Astrand Bicycle test, without careful control and severe motivation is not highly efficient in measuring individuals without cycling experience. Investigations of non-cycling populations are necessary before this could be ascertained.

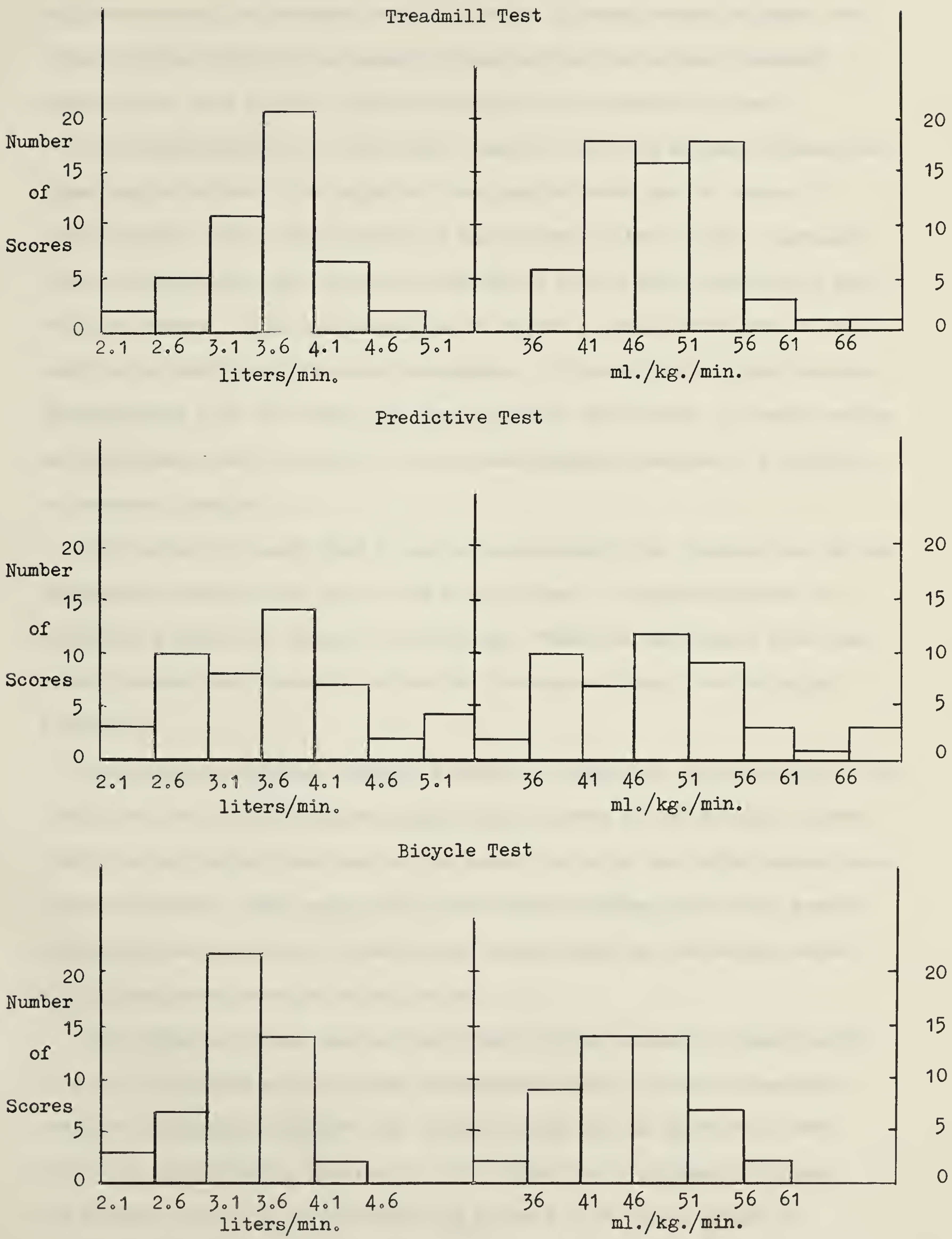
The fact that the predictive test results in a mean of the same magnitude as the treadmill test suggests that it predicts maximal oxygen consumption with considerable accuracy. Before any conclusions are drawn, however, the following discussion should be carefully considered.

It was found, using a t-test for homogeneity of variance (39:143), that

the modified Astrand-Ryhming test had a significantly greater variance ($p = .01$) than either of the actual tests. No difference was found in a variance comparison of the actual tests. Rodahl (71:284), one of the co-authors of the Hettinger, et al study (45) reports standard deviations of 0.28 liters per minute for the Astrand Bicycle test and 0.48 liters per minute for the Astrand-Ryhming nomogram. When converted to variance estimates and tested for homogeneity, they were found to be significant at the .01 level.

In an attempt to analyse the reasons for such variance differences, the distributions of scores obtained on the tests in this study were graphed in the form of histograms and are shown in Figure X. It can be readily seen that the range of values on the Astrand-Ryhming test (2.26 - 5.37) is greater than that of the Mitchell, Sproule and Chapman test (2.53 - 4.73) or the Astrand Bicycle test (2.50 - 4.54). Possible reasons for this spread are: 1.) It was observed in the Mitchell, et al test that sixteen of twenty-two subjects that attempted greater test loads than the one at which they reached their maximum oxygen consumption, as determined by the test criterion, attained a value that was greater than their "test maximum". If these higher values were recorded, the upper end of the curve would fill out more and a larger range might result. For example, subject 47 in this study is ranked number 47 on the Mitchell, et al test but the value he eventually reached would have placed him in rank 8. 2.) Although none of the sixteen subjects that attempted greater loads on the Astrand Bicycle test reached a higher oxygen consumption value, it appeared that two factors were at work. (i) The increments outlined in the test seem to be much too large in view of the sudden inability of many subjects to carry on with the test, and (ii) Muscle fatigue, specifically the quadriceps, was most often the reason that subjects gave for terminating the test. Both of these factors would tend to reduce the upper range of the oxygen consumption distribution. If some

FIGURE X SCORE DISTRIBUTIONS (N = 48)



way were devised to overcome this difficulty by using a more suitable increment system then the variances of these actual tests might increase enough to be more in line with the variance of the predictive test.

The fact must not be overlooked, however, that the Astrand-Ryhming nomogram was calculated from emperical data and is based upon a spread of actual values. The consolidation of these scores into a single regression line and subsequent application of individual values could conceivably magnify any errors. This would lead one to expect a greater variance in maximal values predicted from such a nomogram. It seems obvious that detailed investigation into the causes of these variance differences is needed before any confidence can be placed in the Astrand-Ryhming nomogram as a predictor of aerobic capacity.

The author is aware that a lack of homoscedasticity violates one of the assumptions required for use of the F-ratio test. Ferguson relieves the situation somewhat by making the statement, "Moderate departures from homogeneity should not seriously affect the inferences drawn from the data", (39:240).

Correlation analyses revealed a number of important relationships. The predictive test maximal oxygen uptake values proved to be as highly correlated with the values from each of the actual tests as the latter values were with each other. This implies that the Astrand-Ryhming test is as good at predicting the results on either of the actual tests as the actual tests are at predicting results on each other.

The Johnson, Brouha and Darling fitness index correlated significantly ($p = .01$) with each of the oxygen consumption tests. It should be noted that the relationship between the fitness index and the predictive test (0.69) is significantly greater ($p = .01$) than the relationship between the fitness index and the Mitchell, et al test (0.46) when weight is

partialled out. Even though this correlation may be spurious because both tests are based on heart rates, it may also show that the modified Astrand-Ryhming test is better at predicting physical fitness, as measured by Johnson, et al, than is the treadmill test. The data from this study is inadequate to differentiate between these possibilities.

In view of the fact that the predictive test is short, non-exhaustive and simple, in comparison to the actual tests, it would be highly advantageous to use it with confidence. Even though a skilled, knowledgable operator is necessary, the benefit of using a single operator, as opposed to two or more in the actual tests, is obvious.

Additional information has been provided from correlation of height, weight, and surface area with the values just discussed. Height showed a significant relationship with values expressed in liters per minute obtained on the Astrand Bicycle test ($p = .01$), the Mitchell, et al test ($p = .05$) and the Astrand predictive test ($p = .05$). It appears from the following correlations with weight and body surface area that the correlations observed with height are simply a carry over from the weight that generally goes with added height. Weight, as would be expected, correlated significantly ($p = .01$) with all three of the maximal oxygen intake tests when expressed in liters per minute, as did body surface area. With weight partialled out, however, the relationships became significantly negative at the .05 level. Since body surface area is largely determined by body weight, correlations involving these parameters were virtually identical.

No significant relationships occurred between height, weight, or body surface area and either the fitness scores or time run on the Johnson, Brouha and Darling test.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to evaluate the modified Astrand-Ryhming nomogram as an estimator of maximal oxygen consumption, as measured by the Mitchell, Sproule and Chapman Maximal Oxygen Intake test, and the modified Astrand Bicycle Ergometer test of Maximal Oxygen Uptake. The oxygen consumption values were also correlated with height, weight, and body surface area as well as the fitness score and time run on the Johnson, Brouha and Darling test of Physical Fitness.

Forty-eight physically active males, aged 17 to 35 comprised of students and staff from the University of Alberta and soldiers stationed at Greisbach Barracks, Edmonton, Alberta made up the sample. On the initial visit to the laboratory, each subject's height and weight were recorded and the physical fitness test was administered. Each participant then executed, on succeeding days, the three oxygen uptake tests in a definite sequence determined by permutations. Sequences were assigned on a chance basis.

Tests were performed on a treadmill with a speed range of 0 to 15 miles per hour and a Monark Bicycle Ergometer. Gas analyses were performed using a Beckman E-2 oxygen analyser and a Godart Capnograph carbon dioxide analyser. Accuracy was confirmed by the Scholander method. Heart rates were recorded with a Sanborn 100 Viso-Electrocardiograph.

Pearson Product-moment correlation coefficients and a two-way analysis of variance provided the basis for the statistical analysis.

In terms of liters per minute, the modified Astrand-Ryhming nomogram produced significant correlations ($p = .01$) of 0.67 with the Mitchell, *et al* test, and 0.62 with the modified Astrand Bicycle test. The treadmill test correlated 0.51 with the maximal bicycle test. With body weight partialled out the correlations were again significant ($p = .01$) and equal to 0.53, 0.47 and 0.39 respectively.

Fitness scores on the Johnson, Brouha and Darling test produced significant correlations ($p = .01$) of 0.38 with the treadmill test, 0.46 with the maximal bicycle test, and 0.55 with the predicted test in terms of liters per minute. Corresponding values in milliliters per kilogram of body weight per minute were 0.46, 0.55 and 0.67 respectively.

Height correlated significantly with the Astrand Bicycle test ($p = .01$), the Mitchell, et al test ($p = .05$) and the predictive test ($p = .05$) in terms of liters per minute.

Weight and body surface area produced equivalent results which were significant with all three of the oxygen consumption tests in terms of liters per minute ($p = .01$) and with the two actual tests (negative relationship) in terms of milliliters per kilogram of body weight per minute ($p = .05$).

Fitness scores and endurance measured on the Johnson, et al test did not correlate significantly with height, weight, or body surface area.

Within the limits of this study, the following conclusions have been made:

1. For the population studied, the Mitchell, Sproule and Chapman Maximal Oxygen Intake test and the modified Astrand-Ryhming Nomogram for Prediction of Maximal Oxygen Uptake, yielded significantly higher mean values than the modified Astrand Bicycle Ergometer test of Maximal Oxygen Uptake.

2. Statistically equivalent means were obtained on the modified Astrand-Ryhming Nomogram and the Mitchell, Sproule and Chapman Maximal Oxygen Intake test.

3. The Astrand-Ryhming Nomogram produced a significantly greater variance than did the modified Astrand Bicycle Ergometer test and the Mitchell, Sproule and Chapman test.

4. The Astrand-Ryhming Nomogram was able to predict maximal oxygen intake values on the modified Astrand Bicycle Ergometer test and the Mitchell,

Sproule and Chapman test as well as the latter tests were able to predict values on each other.

5. As measured by the Johnson, Brouha and Darling test of Physical Fitness, the Astrand-Ryhming Nomogram was able to predict physical fitness as well as the modified Astrand Bicycle ergometer test and significantly better than the Mitchell, Sproule and Chapman test.

6. Body weight and surface area produced equivalent significant correlations with the three tests of maximal oxygen uptake in terms of liters of oxygen consumed per minute.

7. Body height, weight and surface area did not show any significant relationships with the Johnson, Brouha and Darling fitness index or endurance.

8. Correlation coefficients involving body weight and body surface area proved to be virtually identical.

BIBLIOGRAPHY

1. Asmussen, E., Bøje, O., "Body Temperature and Capacity for Work", Acta Physiologica Scandinavica, vol. 10 (1945), pp. 1 - 22.

2. Asmussen, E., Hemmingsen, I., "Determination of Maximum Working Capacity at Different Ages in Work with the Legs or with the Arms", Scandinavian Journal of Clinical and Laboratory Investigation, vol. 10 (1958), pp. 67 - 71.

3. Astrand, I., "Aerobic Work Capacity in Men and Women with Special Reference to Age", Acta Physiologica Scandinavica, vol. 49 (Supplementum 169, 1960), pp. 45 - 60.

4. Astrand, I., "The Physical Work Capacity of Workers 50 - 64 Years Old", Acta Physiologica Scandinavica, vol. 42 (1958), pp. 73 - 86.

5. Astrand, P. -O., Experimental Studies of Physical Working Capacity in Relation to Sex and Age, Copenhagen: Munksgaard, 1952, pp. 23 - 37, 15 - 27, 110, 148.

6. Astrand, P.-O., "Maximum Working Capacity for the Two Sexes and For Different Age Groups From 41 to 30 Years", Acta Physiologica Scandinavica, vol. 25, (Supplementum 89, 1951), pp. 3 - 4.

7. Astrand, P.-O., "Human Physical Fitness with Special Reference to Sex and Age", Physiological Reviews, vol. 36 (1956), pp. 307 - 335.

8. Astrand, P.-O., Work Tests with the Bicycle Ergometer, AB Cykelfabriken Monark, Varberg, pp. 1 - 14.

9. Astrand, I., Astrand, P.-O., Christensen, E., Hedman, R., "Circulatory and Respiratory Adaptation to Severe Muscular Work", Acta Physiologica Scandinavica, vol. 50 (1960), pp. 254 - 258.

10. Astrand, I., Astrand, P.-O., Rodahl, K., "Maximal Heart Rate During Work in Older Men", Journal of Applied Physiology, vol. 14 (1959), pp. 562 - 566.

11. Astrand, P.-O., Ryhming, I., "A Nomogram for Calculation of Aerobic Capacity (Physical Fitness) from Pulse Rate During Submaximal Work", Journal of Applied Physiology, vol. 7 (1954), pp. 218 - 221.

12. Astrand, P.-O., Saltin, B., "Oxygen Uptake and Muscular Activity", Journal of Applied Physiology, vol. 16 (1961), pp. 977 - 981.

13. Astrand, P.-O., Saltin, B., "Oxygen Uptake During the First Minutes of Heavy Muscular Exercise", Journal of Applied Physiology, vol. 16, (1961), pp. 971 - 976.

14. Balke, B., Ware, R.W., "An Experimental Study of 'Physical Fitness' of Air Force Personnel", U.S. Armed Forces Medical Journal, vol. 10, (1959), p. 675.

15. Binkhorst, R.A., van Leeuwen, P., "A Rapid Method for the Determination of Aerobic Capacity", International zeitschrift fur Angewandte Physiologie, vol. 19 (1963), pp. 459 - 467.

16. Bock, A.V., Van Caulaert, C., Dill, D.B., Folling, A., Hurxthal, L.M., "Studies in Muscular Activity. III Dynamical Changes Occurring in Man at Work", Journal of Physiology, vol. 66 (1928), pp. 136 - 161.

17. Borg, G., Dahlstrom, H., "The Reliability and Validity of a Physical Work Test", Acta Physiologica Scandinavica, vol. 55, (1962), pp. 353 - 361.

18. Brouha, L., Heath, C.W., "Resting Pulse and Blood Pressure Values in Relation to Physical Fitness in Young Men", New England Journal of Medicine, vol. 228 (1943), pp. 473.

19. Brouha, L., Radford, E.P., "The Cardiovascular System in Muscular Activity", Science and Medicine of Exercise and Sports, Editor - W.H. Johnson, Harper and Brothers, New York, 1960.

20. Brozek, J., Taylor, H.L., "List of Motor Functions in Investigations of Fitness", American Journal of Psychology, vol. 67 (1954), pp. 590 - 611.

21. Buskirk, E., "Relationship in Man Between the Maximal Oxygen Intake and Components of Body Composition", Unpublished Doctoral Thesis, University of Minnesota, December, 1953.

22. Buskirk, E., Taylor, H.L., "Maximal Oxygen Intake and its Relation to Body Composition with Special Reference to Chronic Physical Activity and Obesity", Journal of Applied Physiology, vol. 11 (1957), pp. 72 - 78.

23. Campbell, J.W., Numerical Tables, Douglas Printing Co. Ltd., Edmonton, 1946.

24. Chapman, C.B., Mitchell, J.H., Sproule, B.J., Polter, D., Williams, B., "The Maximal Oxygen Intake Test in Patients with Predominant Mitial Stenosis, a preoperative and postoperative study", Circulation, vol. 22, (1960), p. 4.

25. Cohn, J.E., Carroll, D.G., Armstrong, B.W., Shepard, R.H., Riley, R.L., "Maximal Diffusing Capacity of the Lung in Normal Male Subjects of Different Ages", Journal of Applied Physiology, vol. 6 (1954), pp. 588 - 597.

26. Collins, Warren E., Inc. (Publishers) Clinical Spirometry, 1961.

27. Consolazio, C.F., Johnson, R.E., Marek, E., Metabolic Methods, C.V. Mosby Co., St. Louis, 1951, p. 373.

28. Consolazio, C.F., Johnson, R.E., Pecora, L.J., Physiological Measurements of Metabolic Functions in Man, McGraw-Hill Book Co., New York, 1963, pp. 6 - 7, 27.

29. Coyne, L.L., "The Relationship of Maximal Oxygen Intake to Body Composition and Total Body Weight in Active Males", Unpublished Master's Thesis, University of Alberta, Edmonton, August 1963.

30. Cullembine, H., Bibile, S.W., Wikramanayake, T.W., Watson, R.S., "Influence of Age, Sex, Physique, and Muscular Development on Physical Fitness", Journal of Applied Physiology, vol. 2 (1950), pp. 488 - 511.

31. Cumming, C.R., Danziger, R., "Validity of Pulse Rate Determination of Working Capacity", Pediatrics, vol. 32 (1963), pp. 202 - 208.

32. Cunningham, D.A., "The Effects of Breathing High Concentrations of Oxygen on Treadmill Performance and Selected Physiological Variables", Unpublished Master's Thesis, University of Alberta, Edmonton, August 1963.

33. Dempsey, J.A., "The Prediction of Basal and Maximal Oxygen Consumption from Various Body Measurements", Unpublished Master's Thesis, University of Alberta, Edmonton, August 1963.

34. de Vries, H.A., Klafs, C.E., "Prediction of Maximal Oxygen Intake from Submaximal Tests", Physiology of Exercise Research Laboratory, Long Beach, California, March 1964.

35. Dill, D.B., Talbott, J.H., Edwards, H.T., "Response of Several Individuals to a Fixed Task", Journal of Physiology, vol. 69 (1930), pp. 267.

36. Dixon, W.J., Massey, F.J., Introduction to Statistical Analysis, McGraw-Hill Book Co., New York, 1951.

37. Erickson, L., Simonson, E., Taylor, H.L., Alexander, H., Keys, A., "The Energy Cost of Horizontal and Grade Walking on the Motor Driven Treadmill", American Journal of Physiology, vol. 145 (1946), pp. 391.

38. Ehret, W.F., Smith's College Chemistry, New York, D. Appleton-Century Co. Inc., 1946, p. 649.

39. Ferguson, G.A., Statistical Analysis in Psychology and Education, New York: McGraw-Hill Book Company, Inc., 1959.

40. Ford, A.B., Hellerstein, H.K., "The Correlation of Pulmonary Ventilation and Energy Expenditure", Clinical Research, vol. 6, (1958), p. 314.

41. Garrett, H.E., Statistics in Psychology and Education, Longmans, Green and Co., 1960, pp. 291 - 295.

42. Goodale, W.T., Gorlin, R., Sawyer, C.G., Dexter, L., Whittenberger, J.L., Haynes, F.W., "The Effect of Exercise on Circulatory Dynamics of Normal Individuals", Journal of Applied Physiology, vol. 3 (1951), p. 439.

43. Henschel, A., Taylor, H.L., Keys, A., "Experimental Malaria in Man - Physical Deterioration and Recovery", Journal of Clinical Investigation, vol. 29 (1950), pp. 52 - 59.

44. Hill, A.V., Muscular Activity, Baltimore: Williams and Wilkins, 1926, pp. 115.

45. Hettinger, T., Birkhead, N.C., Horvath, J.M., Issekutz, B., Rodahl, K., "Assessment of Physical Work Capacity", Journal of Applied Physiology, vol. 16 (1961), pp. 153 - 156.

46. Hill, A.V., Muscular Activity, Baltimore: Williams and Wilkins, 1926, p. 115.

47. Hill, A.V., Long, C.N.H., Lupton, H., "Muscular Exercise, Lactic Acid and Supply and Utilization of Oxygen", Proceedings of the Royal Society of London - Series B., Vol. 97, (1925), p. 155.

48. Hill, A.V., Lupton, H., "Muscular Exercise, Lactic Acid, and the Supply and Utilization of Oxygen", Quarterly Journal of Medicine, vol. 16 (1923), pp. 135 - 171.

49. Huckabee, W.E., Judson, W.E., "Role of Anaerobic Metabolism in Performance of Mild Muscular Work: Relationship to Oxygen Consumption and Cardiac Output, and the Effect of Congestive Heart Failure", Journal of Clinical Investigation, vol. 37, (1958), pp. 1577 - 92.

50. Issekutz, B., Birkhead, N.C., Rodahl, K., "Use of Respiratory Quotients in Assessment of Aerobic Work Capacity", Journal of Applied Physiology, vol. 17 (1962), pp. 47 - 50.

51. Johnson, R.E., Brouha, L., Darling, R.C., "A Test of Physical Fitness for Strenuous Exertion", Revue Canadienne du Biologie, vol. 1 (1942), pp. 491 - 503.

52. Karpovich, P.V., Physiology of Muscular Activity, London: W.B. Saunders Company, 1959.

53. Keys, A., Brozek, J., Henschel, A., Michelsen, O., Taylor, H.L., The Biology of Human Starvation, Minneapolis: University of Minnesota Press, 1950.

54. Knehr, C.A., Dill, D.B., Neufeld, W., "Training and its Effects on Man at Rest and at Work", American Journal of Physiology, vol. 136, (1942), pp. 148.

55. Krogh, A., Lindhard, J., "A Comparison Between Voluntary and Electrically Induced Muscular Work in Man", Journal of Physiology, vol. 51 (1917), pp. 182 - 201.

56. Krogh, A., Lindhard, J., "The Relative Values of Fats and Carbohydrates as Sources of Muscular Energy", Biochemical Journal, vol. 14 (1920), p. 290.

57. Lange Andersen, K., Respiratory Recovery from Muscular Exercise of Short Duration, Oslo: Oslo University Press, 1959, pp. 45.

58. Lundgren, N.P.V., "The Physiological Effects of Time Schedule Work on Lumber - Workers", Acta Physiologica Scandinavica - Supplementum 13, vol. 41 (1946), pp. 1 - 137.

59. Master, A.M., "The Two-Step Exercise ECG: A Test for Coronary Insufficiency", Annals of Internal Medicine, vol. 32 (1950), pp. 842 - 48.

60. Metheny, E.L., Brouha, L., Johnson, R.E., Forbes, W.H., "Some Physiologic Responses of Women and Men to Moderate Strenuous Exercise", American Journal of Physiology, vol. 137, (1942), p. 318.

61. Mitchell, J.H., Sproule, B.J., Chapman, C.B., "The Physiological Meaning of the Maximal Oxygen Intake Test", Journal of Clinical Investigation, vol. 37 (1958), pp. 538 - 546.

62. Morehouse, L.E., Miller, A.T., Physiology of Exercise, The C.V. Mosby Co., St. Louis (1959).

63. Newton, J.L., "The Assessment of Maximal Oxygen Intake", Journal of Sports Medicine and Physical Fitness, vol. 3 (1963), pp. 164 - 169.

64. Passmore, R., Durnin, J.V., "Human Energy Expenditure", Physiological Reviews, vol. 35 (1955), p. 801.

65. Peters, J., Van Slyke, M., Quantitative Clinical Chemistry, vol. 2 (Methods), Williams and Wilkins, Baltimore, (1932), p. 48.

66. Robinson, S., "Experimental Studies of Physical Fitness in Relation to Age", Arbeitsphysiologie, vol. 10 (1938), pp. 251.

67. Robinson, S., "Metabolic Adaptations to Exhausting Work as Affected by Training", American Journal of Physiology, vol. 133 (1940), pp. 428.

68. Robinson, S., "Temperature Regulation in Exercise", Pediatrics - Supplement 32, (1963), pp. 691 - 702.

69. Robinson, S., Edwards, H.T., Dill, D.B., "New Records in Human Power", Science, vol. 85 (1939), pp. 401 - 410.

70. Rodahl, K., Astrand, P.-O., Birkhead, N.C., Hettinger, T., Issekutz, B., Jones, D.M., Weaver, R., "Physical Work Capacity", Archives of Environmental Health, vol. 2 (1961), pp. 499 - 510.

71. Rodahl, K., Horvath, S.M., (Editors), Muscle as a Tissue, Mc-Graw-Hill Book Company, New York, 1962, pp. 284 - 5.

72. Rowell, L.B., Taylor, H.L., Wang, Y., cited in Taylor, H.L., Wang, Y., Rowell, L., Blomquist, G., "The Standardization and Interpretation of Submaximal and Maximal Tests of Working Capacity", Pediatrics - Supplementum, vol. 32 (1963), pp. 703 - 722.

73. Ruck, T.C., Fulton, J.F., Medical Physiology and Biophysics, W.B. Saunders Company, Philadelphia, 1955, pp. 789 - 838.

74. Scholander, P.F., "Analyzer for Accurate Estimation of Respiration Gases in One-Half Cubic Centimeter Samples", Journal of Biological Chemistry, vol. 167 (1947), pp. 235 - 250.

75. Sexton, A.W., "Value of Longitudinal Studies of Exercise Fitness Tests", Pediatrics - Supplement 32, (1963), pp. 730 - 736.

76. Sjöstrand, T., "Changes in the Respiratory Organs of Workmen at an Ore Smelting Works", Acta Medica Scandinavica, vol. 196, (Supplement, 1947).

77. Sjöstrand, T., "Volume and Distribution of Blood and their Significance in Regulating the Circulation", Physiological Reviews, vol. 33, (1953), pp. 202.

78. Steele, R.G.D., Torrje, J.H., Principles and Procedures of Statistics, McGraw-Hill Book Co. Inc., New York, 1960, pp. 107 - 109.

79. Taylor, C., "Effect of Work-Load and Training on Heart Rate", American Journal of Physiology, vol. 135 (1941), pp. 27 - 42.

80. Taylor, C., "Some Properties of Maximal and Submaximal Exercise with Reference to Physiological Variations and the Measurement of Exercise Tolerance", American Journal of Physiology, vol. 142 (1944), pp. 200 - 212.

81. Taylor, H.L., Brozek, J., "Evaluation of Fitness", Federation Proceedings, vol. 3 (1944), pp. 216.

82. Taylor, H.L., Buskirk, E., Henschel, A., "Maximal Oxygen Intake as an Objective Measure of the Cardio-Respiratory Performance", Journal of Applied Physiology, vol. 8 (1955), pp. 73 - 80.

83. Taylor, H.L., Henschel, A., Brozek, J., Keys, A., "The Effects of Bed Rest on Cardiovascular Function and Work Performance", Journal of Applied Physiology, vol. 2 (1949), pp. 223 - 239.

84. Taylor, H.L., Wang, Y., Rowell, L., Blomquist, G., "The Standardization and Interpretation of Submaximal and Maximal Tests of Working Capacity", Pediatrics: Supplementum, vol. 32 (1963), pp. 703 - 722.

85. von Döbeln, W., "A Simple Bicycle Ergometer", Journal of Applied Physiology, vol. 7 (1954), pp. 222 - 224.

86. von Döbeln, W., Engstrom, C.G., Strom, G., "Physical Working Capacity of Swedish Air Force Pilots", Journal of Aviation Medicine (Aerospace Medicine), vol. 30 (1959), pp. 162 - 166.

87. von Döbeln, W., "Maximal Oxygen Intake, Body Size, and Total Hemoglobin in Normal Man", Acta Physiologica Scandinavica, vol. 38 (1957), p. 193.

88. Wahlund, H., "Determination of Physical Working Capacity", Acta Medica Scandinavica, vol. 132 (Supplementum 215, 1948), pp. 9 - 78.

89. Walker, H.M., Lev, J., Statistical Inference, Henry Holt and Co., New York, 1953.

90. Watson, R.W., "Cardio-Respiratory Effects of Ice Hockey Upon Treadmill Performance", Unpublished Master's Thesis, University of Alberta, Edmonton, August 1964.

91. Waxman, W.W., "Physical Fitness Developments for Adults in the YMCA", Exercise and Fitness, University of Illinois and the Athletic Institute, 1959, pp. 183 - 192.

92. Welch, B.E., Riendeau, P., Crisp, C.E., Isenstein, R.S., "Relationship of Maximal Oxygen Consumption to Various Components of Body Composition", Journal of Applied Physiology, vol. 12 (1958), pp. 395 - 398.

93. Williams, C.G., Bredell, G.A.G., Wyndham, C.H., Strydom, N.B., Morrison, J.F., Peter, J., Fleming, P.W., Ward, J.S., "Circulatory and Metabolic Reactions to Work in Heat", Journal of Applied Physiology, vol. 17 (1962), pp. 625.

94. Wyndham, C.H., Strydom, N.B., Maritz, J.S., Morrison, J.F., "Maximum Oxygen Intake and Maximum Heart Rate During Strenuous Work", Journal of Applied Physiology, vol. 14 (1959), pp. 927 - 936.

95. Wyndham, C.H., Ward, J.S., "An Assessment of the Exercise Capacity of Cardiac Patients", Circulation, vol. 16, (1957), pp. 384 - 93.

APPENDIX A

STATISTICAL TREATMENT

Correlation Coefficients. Correlation coefficients between the three maximal oxygen consumption tests and the Johnson, Brouha and Darling Physical Fitness test were obtained by use of the following IBM program.

PROGRAM: 1620-013 Simple Correlations

STATEMENT OF PROBLEM: Given N sets of observations $(X_{i1}, X_{i2}, \ldots, X_{ip})$, $i = 1,2,\ldots,N$, on p random variables. $X_1, X_2, \ldots, X_p$, it is required to compute

(a) means, $\bar{X}_j = \frac{1}{N} \sum_{i=1}^{N} X_{ij}$, $j = 1,2,..,p$

(b) variances, $s_j^2 = \frac{1}{N-1} \left[\sum_i X_{ij}^2 - \frac{1}{N}\left(\sum_i X_{ij} \right)^2 \right]$, $j = 1,2,\ldots,p$

(c) standard deviations, s_j , $j = 1,2,\ldots,p$

(d) correlation coefficients,

$$r_{jk} = \frac{\frac{1}{N-1} \left[\sum_i X_{ij} X_{ik} - \frac{1}{N} \sum_i X_{ij} \sum_i X_{ik} \right]}{s_j s_k}$$

$j = 1,2,\ldots,p-1$

$k = j+1,\ldots,p$

Significance of the Difference Between Two Correlation Coefficients for Correlated Samples. To test the difference between any two correlations based on correlated samples a t value was calculated by the formula (89:257):

$$t = \frac{(r_{12} - r_{13}) \sqrt{(N-3)(1+r_{23})}}{\sqrt{2(1 - r_{12}^2 - r_{13}^2 - r_{23}^2 + 2r_{12}r_{13}r_{23})}}$$

The t was tested for significance with N-3 degrees of freedom.

Analysis of Variance. An analysis of variance designed to test the significance of the difference between means obtained from correlated groups (two criteria of classification) was used in this study (41:291).

No.	MSC	AA	AP	$\sum_{r=1}^{3} X$	$\sum_{r=1}^{3} X^2$
1	54.81	51.34	56.82	162.97	8868.44
2	49.77	43.02	52.44	145.23	7077.73
3	45.84	42.23	37.60	125.67	5298.44
. . .	. . .	. . .	. . .	. . .	. . .
48	54.17	56.72	37.41	148.30	7551.06
$\sum_{i=1}^{48} X$	2324.10	2318.97	2226.52	X..=6869.59	
$\sum_{i=1}^{48} X^2$	115,295.30	114,321.32	105,740.83		$\sum\sum X^2$=335,357.45

A. Sum of Squares

1. Correction. $\frac{(\sum X)^2}{N} = \frac{(6869.59)^2}{144} = 327{,}717.13$

2. Total Sum of Squares Around the General Mean.

$$SS_T = (54.81^2 + 49.77^2 + \ldots + 37.41^2) - 327{,}717.13$$
$$= 335{,}357.49 - 327{,}717.13 = 7{,}640.36$$

3. Sum of Squares Between the Means of Tests.

$$SS_{trials} = (2324.10)^2 + (2318.97)^2 + (2226.52)^2 - C$$
$$= 328{,}032.99 - 327{,}717.13 = 315.86$$

4. Sum of Squares Among the Means of Subjects

$$SS_{subjects} = (162.97)^2 + (145.23)^2 + \ldots + (148.30)^2 / 3$$
$$= 997{,}026.84/3 - 327{,}717.13 = 4{,}625.15$$

5. Interaction Sum of Squares

$$\text{Int. } SS = SS_T - (SS_{subjects} + SS_{trials})$$
$$7{,}640 - (4{,}625.15 + 315.86) = 2699.35$$

B. Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F
Between tests	315.86	(C-1)=(3-1)=2	$\frac{315.86}{2}$=157.93	$\frac{157.93}{28.72}$=5.50
Between Subjects	4625.15	(R-1)=(48-1)=47	$\frac{4625.86}{47}$= 98.41	$\frac{98.41}{28.72}$=3.43
Interaction	2699.35	(R-1)(C-1)=47X2=94	$\frac{2699.35}{94}$= 28.72	
Total	7640.36	143		

Tests		Subjects	
Degrees of Freedom	= 2/94	Degrees of Freedom	= 47/94
F at .01	= 4.82	F at .01	= 1.73

Duncan's New Multiple Range Test. The new Duncan Multiple-Range test (78:107) was developed in 1955 and is designed to permit comparison of each treatment mean with every other mean.

$$S_{\bar{X}} = \frac{(\text{error mean square})}{r}$$

Least Significant Ranges (R) (.01)

Value of p	2	3
Significant Studentized Ranges (SSR)	3.71	3.86
Rp = ($S_{\bar{X}}$ SSR) = LSR Least Significant Range	.212	.221

df = (R-1)(C-1)

Rank of Means (liters/min.)

3.425 3.664 3.674

Method of Testing the Differences

Largest - Smallest	= 3.674 - 3.425 =	.249	.221	Significant
Largest - Second Smallest	= 3.674 - 3.664 =	0.010	.212	Not Significant
Second Smallest - Smallest	= 3.664 - 3.425 =	.239	.212	Significant

Significance of the Difference Between Two Means for Correlated Samples.

$$S_D^2 = \frac{\sum D^2}{N-1} - \bar{D}^2$$

$$S_{\bar{D}}^2 = \frac{S_D^2}{N}$$

$$t = \frac{\bar{D}}{S_{\bar{D}}} = \frac{\bar{D}}{\frac{S_D^2}{N}}$$

degrees of freedom = N-1

Standard Deviation.

$$s = \sqrt{\frac{X^2}{N} - \bar{X}^2}$$

Significance of a Correlation Coefficient.

$$t = r\sqrt{\frac{N-2}{1-r^2}}$$

degrees of freedom = N-2

APPENDIX B

INDIVIDUAL SCORE SHEETS

Name:	Age:	Wt.	Ht.	Max. VO_2	1. Astrand.	Ast. Pred.	T.B.H.	M.S.C.		Resting HR.
Address:	Smokes:			Dates:						
Phone:				R.Q.						

ASTRAND NOMOGRAM

Load kpm.	Pulse rates (after mins. of work) 1	2	3	4	5	6	7	8	9	10
900										
1200										

Prediction : L./min.

" : ml./Kg.B.W.

ASTRAND MAX VO_2 TEST.

Load kpm.	Exercise P.R. (mins.) Pre	1	2	3	4	5	6	Sub-M VO_2	Recovery P.R. 15s	30	45	1	1.30	2	3.0	4	5			
600																				
900																				
1200																				
1500																				
1800																				
1950																				
2100																				

Max : L./min. ml./kg.B.W.

Work done at MaxVO_2 : kpm. Max P.R.

JOHNSON-BROUHA RUN : Date / / Max. P.R.: Duration of run: secs.

	15	30	45	1	1.30	2	2.30	3	3.30	4	4.30	5		15	30	45	1	1.30	2	2.30	3	3.30	4	4.30	5		1-1.30	2-2.30	3-3.30	PFI = 00 / 2x =

GAS ANALYSIS SHEET

300 KPM
600
900
1200
1500
1800
1950
2100

NAME______________________

DATE______________________

T = __________ °C
B.P. = __________ mm. Hg
Factor = __________

FeO_2 = __________ $X \frac{2.5}{1000}$ = __________ F_IO_2 = 20.94

FeO_2 = __________(corr.) F_ICO_2 = 00.03

$FeCO_2$ = __________ F_IN_2 = 79.03

FeN_2 = __________

V_EATPS = __________ l./min.

V_ESTPD = __________ X __________ = __________ l./min.

V_ISTPD = __________ X $\frac{\_\_\_\_\_\_\_\_\_\_}{.7903}$ = __________ l./min.

VO_2 = (__________ X .2094) - (__________ X __________) = __________ l./min

VCO_2 = (__________ X _____) - (__________ X .0003) = __________ l./min

R. Q. = __________

Smoker __________ Number __________

Health (general)__________

Height__________inches

Weight__________pounds __________kilograms

Birthday__________

APPENDIX C

RAW SCORES

INFORMATION PERTAINING TO INDIVIDUAL SUBJECT'S PHYSICAL CHARACTERISTICS

Subject	Age	Height (Inches)	Weight		Smoker			
			Pounds	Kilograms	Yes	No	5	5
1	23	68	154.5	70.08		X		
2	20	69.5	178.25	80.85		X		
3	19	71	180	81.65		X		
4	23	78	189	86.73		X		
5	25	70	163	73.94		X		
6	33	73	170.5	77.34		X		
7	24	71	172	78.02		X		
8	25	68.5	170.5	77.34	Pipe			
9	30	71	163	73.94	X		X	
10	23	73	170	77.11		X		
11	26	69.5	168	76.20		X		
12	29	74	177	80.29		X		
13	22	70.5	170	77.11		X		
14	18	69	139	63.05	X			X
15	22	72	169	76.66		X		
16	25	71.75	184	83.46		X		
17	23	70	170	77.11		X		
18	24	67.5	156	70.76		X		
19	17	69	145.5	65.00	X			X
20	29	67	155	70.31		X		
21	21	69	168	76.20		X		
22	21	70	173	78.47	X			X
23	18	72.5	148	67.13		X		
24	21	69	153	69.40		X		
25	20	70.25	160	72.58	X			X
26	26	69	185	80.92		X		
27	17	67.5	150	68.03	Pipe			
28	22	69	146	66.23	X			X
29	19	73	194	87.00	X			X
30	19	65	119	53.98	X			X
31	17	70	204	92.53		X		
32	21	67.75	148	67.13	X			X
33	17	66	137.5	62.37	X			X
34	20	72	181.5	82.33		X		
35	25	70.5	175	79.38		X		
36	25	70.25	170	77.11		X		
37	17	68.5	142	64.41	X			X
38	23	72	165.5	75.07		X		
39	21	67	147.5	66.90	X			X
40	21	72	157	71.21	X			X
41	25	66	147.5	66.91		X		
42	24	70	212.5	96.39		X		
43	35	68	168	76.20	X		X	
44	24	73	203	92.08	X			X
45	19	71.5	182	82.55	X			X
46	23	68.5	157	71.21	X			X
47	28	72.5	205	92.99		X		
48	20	71	151	68.49		X		
49	20	67	150	68.04		X		
50	22	67	142.5	64.67	X			X
51	25	67.5	154	69.85		X		
52	17	67.75	142	64.41		X		
53	20	63	142	64.41		X		
54	34	64.5	142	64.41	X			X

Subject	Age	Height	Weight		Smoker			
		(Inches)	Pounds	Kilograms	Yes	No	5	5
55	26	68	158	71.67	X			X
56	22	68.5	154	69.85		X		
57	18	70.5	147.5	66.91	X			X
58	18	69.5	166	75.15	X			X
59	44	69	153.5	69.40		X		
60	38	65.75	143	64.86	X			X
61	38	68	149.5	67.81	X			X
62	42	66	180	81.65	X			X
63	48	67.5	141	63.96	X			X

Surface areas for each subject were calculated from the Du Bois-Meeh formula (Consolazio: 26-27). Results are given in the following table in meters squared.

$$M^2 = W^{0.425} \times H^{0.725} \times 71.84$$

M = meters, W = weight, H = height.

SURFACE AREAS FROM THE DU BOIS-MEEH FORMULA

Subject	Height (inches)	Weight (kilograms)	Surface Area (square meters)	Subject	Height (inches)	Weight (kilograms)	Surface Area (square meters)
1	172.72	70.08	1.831	25	178.44	72.58	1.904
2	176.53	80.85	1.977	26	175.26	80.92	1.968
3	180.34	81.65	2.016	27	171.45	68.03	1.801
4	198.12	86.73	2.214	28	175.26	66.23	1.809
5	177.80	73.94	1.913	29	185.42	87.00	2.114
6	185.42	77.34	2.011	30	165.10	53.98	1.588
7	180.34	78.02	1.977	31	177.80	92.53	2.051
8	173.99	77.34	1.921	32	172.09	67.13	1.796
9	180.34	73.94	1.932	33	167.64	62.37	1.706
10	185.42	77.11	2.008	34	182.88	82.33	2.045
11	176.53	76.20	1.929	35	179.07	79.38	1.982
12	187.96	80.29	2.062	36	178.44	77.11	1.952
13	179.07	77.11	1.960	37	173.99	64.41	1.774
14	175.26	63.05	1.769	38	182.88	75.07	1.968
15	182.88	76.66	1.991	39	170.18	66.90	1.774
16	182.25	83.46	2.051	40	182.88	71.21	1.924
17	177.80	77.11	1.949	41	167.64	66.91	1.756
18	171.45	70.76	1.831	42	177.80	96.39	2.085
19	175.26	65.00	1.793	43	172.72	76.20	1.896
20	170.18	70.31	1.814	44	185.42	92.08	2.167
21	175.26	76.20	1.921	45	181.61	82.55	2.036
22	177.80	78.47	1.910	46	173.99	71.21	1.852
23	184.15	67.13	1.885	47	184.15	92.99	2.164
24	175.26	69.40	1.844	48	180.34	68.49	1.871

MEAN STEADY STATE HEART RATE FOR THE PREDICTION OF MAXIMAL OXYGEN UPTAKE FROM THE ASTRAND-RYHMING NOMOGRAM

Subject	Mean Heart Rate	Resistance kpm	Subject	Mean Heart Rate	Resistance kpm
1	133	900	25	163	900
2	132	900	26	133	900
3	158	900	27	154	900
4	149	1200	28	167	900
5	157	900	29	130	900
6	132	1200	30	165	900
7	136	900	31	142	900
8	134	1200	32	168	900
9	131	900	33	146	600
10	136	1200	34	134	900
11	143	1200	35	138	900
12	158	900	36	131	1200
13	132	900	37	155	900
14	153	600	38	131	900
15	163	900	39	142	900
16	143	900	40	169	900
17	132	900	41	140	900
18	135	900	42	134	1200
19	167	900	43	153	1200
20	170	900	44	135	900
21	149	900	45	144	900
22	149	900	46	141	900
23	135	900	47	147	1200
24	145	1200	48	142	900

JOHNSON, BROUHA AND DARLING PHYSICAL FITNESS SCORES

Subject	Fitness Score	Subject	Fitness Score	Subject	Fitness Score
1	76.1	17	82.0	33	24.3
2	60.2	18	83.8	34	39.6
3	59.4	19	52.8	35	47.5
4	82.9	20	43.3	36	75.4
5	50.2	21	54.3	37	63.4
6	102.7	22	59.5	38	66.1
7	79.0	23	75.0	39	77.3
8	68.8	24	102.0	40	37.5
9	79.8	25	46.7	41	83.8
10	90.4	26	78.5	42	69.8
11	77.7	27	52.0	43	90.9
12	60.4	28	65.8	44	35.0
13	86.7	29	57.3	45	48.2
14	38.9	30	79.8	46	68.5
15	47.2	31	24.2	47	77.3
16	69.7	32	39.4	48	91.5

CALCULATION OF MAXIMUM OXYGEN UPTAKE FROM PULSE RATE AND WORKLOAD ON A BICYCLE ERGOMETER (3)

	Maximal Oxygen Uptake (L./min.)					Maximal Oxygen Uptake (L./min.)			
Working Pulse	300 kpm/ min.	600 kpm/ min.	900 kpm/ min.	1200 kpm/ min.	Working Pulse	300 kpm/ min.	600 kpm/ min.	900 kpm/ min.	1200 kpm/ min.
120	2.2	3.5	4.8		146		2.4	3.3	4.4
121	2.2	3.4	4.7		147		2.4	3.3	4.4
122	2.2	3.4	4.6		148		2.4	3.2	4.3
123	2.1	3.4	4.6		149		2.3	3.2	4.3
124	2.1	3.3	4.5	6.0	150		2.3	3.2	4.2
125	2.0	3.2	4.4	5.9	151		2.3	3.1	4.2
126	2.0	3.2	4.4	5.8	152		2.3	3.1	4.1
127	2.0	3.1	4.3	5.7	153		2.2	3.0	4.1
128	2.0	3.1	4.2	5.6	154		2.2	3.0	4.0
129	1.9	3.0	4.2	5.6	155		2.2	3.0	4.0
130	1.9	3.0	4.1	5.5	156		2.2	2.9	4.0
131	1.9	2.9	4.0	5.4	157		2.1	2.9	3.9
132	1.8	2.9	4.0	5.3	158		2.1	2.9	3.9
133	1.8	2.8	3.9	5.3	159		2.1	2.8	3.8
134	1.8	2.8	3.9	5.2	160		2.1	2.8	3.8
135	1.7	2.8	3.8	5.1	161		2.0	2.8	3.7
136	1.7	2.7	3.8	5.0	162		2.0	2.8	3.7
137	1.7	2.7	3.7	5.0	163		2.0	2.8	3.7
138	1.6	2.7	3.7	4.9	164		2.0	2.7	3.6
139	1.6	2.6	3.6	4.8	165		2.0	2.7	3.6
140	1.6	2.6	3.6	4.8	166		1.9	2.7	3.6
141		2.6	3.5	4.7	167		1.9	2.6	3.5
142		2.5	3.5	4.6	168		1.9	2.6	3.5
143		2.5	3.4	4.6	169		1.9	2.6	3.5
144		2.5	3.4	4.5	170		1.8	2.6	3.4
145		2.4	3.4	4.5					

CORRECTIONS FOR AMERICAN METER CO. GAS METER #802

This meter was tested for its volume determinations using as standards the large Tissot tank in the Faculty of Physical Education Laboratory and a smaller Tissot in the Cardio-pulmonary Laboratory at the University Hospital. It was found to be recording volume readings in excess of actual volumes pumped, as indicated by the Tissot tanks. A second American Meter Co. gas meter, in use in the University Hospital, was found to give extremely accurate readings when compared to the same Tissot tanks.

The data collected was analyzed and a regression equation calculated. This equation was found to be,

$$Y = .22770 + .943099\, X$$

where Y = corrected volume

and X = volume as read on the American Meter Co. Gas Meter #802.

This regression equation was then used to calculate a complete set of correction tables. These tables also incorporate a factor for loss of volume during oxygen and carbon dioxide analysis, with the factor being considered as 300 c.c.

CORRECTIONS FOR THE BECKMAN E-2 OXYGEN ANALYZER.

The accuracy of this instrument was tested against two micro-Scholander instruments operated by laboratory technicians in the Cardio-pulmonary Laboratory of the University of Alberta Hospital and the laboratory of the Department of Physiology at the University of Alberta.

The values obtained with the two Scholanders were averaged and a regression equation based on the Beckman reading and the Scholander values was calculated. This equation was found to be,

$$Y' = .893X + 2.22$$

where Y' = the corrected percentage of oxygen

and X = the percentage of oxygen as read on the Beckman E-2 analyzer.

The discrepancy was found to be due to impure nitrogen which was used as a calibration gas.

Based on the above regression equation, a second regression line was calculated which permitted direct correction of oxygen consumption values. This equation was found to be,

$$Y' = .871X + .0044$$

where Y' = corrected oxygen consumption in liters per minute

and X = oxygen consumption value obtained on the basis of the uncorrected percentage of oxygen as obtained on the Beckman analyzer.

After testing with the same Micro-Scholanders, the Godart Capnograph infra-red carbon dioxide analyzer was found to give accurate readings.

The raw scores contained in Appendix C have not been corrected for the oxygen discrepancy but have been changed to the corrected volume.

RAW SCORES OBTAINED ON THE MITCHELL, SPROULE AND CHAPMAN MAXIMAL OXYGEN INTAKE TEST

Subject	0%	2½%	5%	7½%	10%	12½%	15%	17½%	20%
	Percent of Treadmill Inclination								
1.									
$\%O_2$	14.69	15.68	15.71	15.18	15.33	15.98	16.30	16.76	
$\%CO_2$	5.10	4.60	4.45	4.95	5.10	4.65	4.40	3.90	
V_ESTPD 1/min	42.63	58.26	62.65	66.37	72.97	86.35	93.60	107.65	
VO_2	2.798	3.171	3.411	3.972	4.198	4.360	4.410	4.588	
2.									
$\%O_2$	16.03	16.00	16.04	16.11	16.05	16.10	17.23		
$\%CO_2$	4.30	4.25	4.40	4.20	4.60	4.40	3.60		
V_ESTPD	65.78	73.69	78.20	85.39	92.79	90.20	125.48		
VO_2	3.341	3.781	3.941	4.273	4.615	4.479	4.701		
3.									
$\%O_2$	15.94	15.90	16.10	16.04	16.55	17.01	17.21	17.66	
$\%CO_2$	4.60	4.40	4.30	4.40	4.25	3.90	3.60	2.80	
V_ESTPD	64.31	67.72	77.26	85.16	95.03	111.23	114.41	151.62 (9 sec.)	
VO_2	3.289	3.532	3.857	4.292	4.214	4.388	4.316	5.178	
4.									
$\%O_2$	15.30	15.10	15.09	15.35	15.54	15.88	16.34		
$\%CO_2$	4.65	4.80	4.90	4.80	4.90	4.70	4.50		
V_ESTPD	58.46	61.69	64.50	73.64	79.50	87.14	91.77		
VO_2	3.454	3.779	3.941	4.276	4.404	4.499	4.253		
5.									
$\%O_2$	15.95	16.00	16.08	16.50	16.80	17.41	17.35		
$\%CO_2$	4.40	4.35	4.40	4.20	4.25	3.50	3.00		
V_ESTPD	50.57	56.44	67.42	75.26	85.47	103.54	108.37		
VO_2	2.607	2.880	3.365	3.396	3.520	3.672	4.067		
6.									
$\%O_2$	16.50	17.00	16.36	16.39	17.31	16.84	17.40	17.71	
$\%CO_2$	3.80	3.60	4.10	4.10	3.30	3.90	3.40	2.90	
V_ESTPD	77.01	94.78	81.99	91.32	121.98	112.44	136.83	71.15 (15 sec. bag)	
VO_2	3.555	3.826	3.977	4.272	4.545	4.679	4.907	2.367	
7.									
$\%O_2$	14.02	14.60	15.20	15.31	15.20	16.16	16.73	17.31	
$\%CO_2$	5.30	5.30	5.10	5.20	5.30	4.90	4.40	3.50	
V_ESTPD	44.25	50.71	59.44	71.94	76.07	97.23	112.18	121.65	
VO_2	3.154	3.360	3.517	4.138	4.461	4.625	4.675	4.468	

SUBJECT	0%	$2\frac{1}{2}$%	5%	$7\frac{1}{2}$%	10%	$12\frac{1}{2}$%	15%	$17\frac{1}{2}$%	20%
8.									
$\%O_2$	15.70	15.73	16.10	16.45	16.48	16.86	17.13	17.13	
$\%CO_2$	4.30	4.30	4.10	3.90	4.00	3.75	3.50	2.40	
V_ESTPD	61.59	65.36	78.07	89.98	92.99	110.36	122.00	95.25	
VO_2	3.386	3.569	3.938	4.189	4.269	4.607	4.757	3.993	
9.									
$\%O_2$	15.70	15.85	15.85	15.44	16.11	16.13	16.71	17.22	17.35
$\%CO_2$	4.50	4.35	4.35	4.80	4.40	4.50	3.95	3.50	2.30
V_ESTPD	53.04	58.48	62.95	63.32	75.08	79.54	94.98	111.15	85.28
VO_2	2.888	3.096	3.332	3.604	3.719	3.897	4.095	4.208	3.359
10.									
$\%O_2$	14.63	14.31	14.30	14.38	14.78	15.34	15.60	16.63	
$\%CO_2$	5.40	5.50	5.80	5.60	5.60	5.20	5.10	4.10	
V_ESTPD	47.84	51.99	55.46	62.84	70.50	86.81	94.24	121.25	
VO_2	3.138	3.606	3.810	4.288	4.454	4.960	5.099	5.315	
11.									
$\%O_2$	15.66	15.35	15.06	15.38	15.93	15.98	16.58	17.28	
$\%CO_2$	4.40	4.40	4.80	4.60	4.60	4.60	4.05	3.30	
V_ESTPD	49.46	52.18	54.91	62.33	76.18	80.78	94.73	108.23	
VO_2	2.731	3.086	3.390	3.629	3.905	4.090	4.216	4.072	
12.									
$\%O_2$	16.14	16.09	16.05	16.14	16.30	16.75	16.88		
$\%CO_2$	4.40	4.25	4.30	4.30	4.35	3.90	3.20		
V_ESTPD	58.36	65.47	69.68	73.49	86.30	99.62	78.25		
VO_2	2.862	3.284	3.522	3.630	4.078	4.242	3.348		
13.									
$\%O_2$	15.75	16.05	16.10	16.15	16.48	16.74	17.09	17.28	
$\%CO_2$	4.40	4.00	4.10	4.10	4.00	3.80	3.80	3.20	
V_ESTPD	54.31	65.28	68.72	79.71	95.75	106.61	123.13	125.32	
VO_2	2.936	3.351	3.466	3.971	4.394	4.599	4.766	4.750	
14.									
$\%O_2$	16.08	15.78	16.16	16.50	16.91	17.18			
$\%CO_2$	4.40	4.50	4.20	4.20	4.10	4.05			
V_ESTPD	57.05	56.13	62.52	75.82	86.69	89.23			
VO_2	2.846	2.999	3.089	3.421	3.485	3.294			
15.									
$\%O_2$	16.15	15.90	16.00	16.18	16.49	16.83	17.59		
$\%CO_2$	4.30	4.45	4.40	4.40	4.30	4.10	3.30		
V_ESTPD	54.12	57.05	63.59	70.13	82.02	95.07	113.11		
VO_2	2.668	2.970	3.238	3.411	3.690	3.926	3.812		
16.									
$\%O_2$	15.29	14.86	15.19	15.81	15.93	16.03	16.59		
$\%CO_2$	4.80	4.90	4.90	4.60	4.60	4.60	4.20		
V_ESTPD	53.40	57.58	68.35	83.01	86.98	98.13	105.63		
VO_2	3.141	3.685	4.089	4.382	4.458	4.906	4.645		

	0%	2½%	5%	7½%	10%	12½%	15%	17½%	20%
17.									
%O_2	15.23	14.90	14.91		15.21	15.40	15.45	15.95	16.74
%CO_2	4.20	4.55	4.75		4.60	4.70	4.90	4.60	4.20
V_ESTPD	47.23	49.64	63.16		64.59	74.03	78.18	91.68	96.29
VO_2	2.889	3.197	4.028		3.900	4.271	4.420	4.677	4.053
18.									
%O_2	16.35	15.96	16.35	16.58	16.85	17.19	17.26	17.44	
%CO_2	4.00	4.30	4.00	3.75	3.65	3.30	3.30	2.60	
V_ESTPD	63.99	71.43	75.23	83.73	98.00	112.87	117.99	109.67	
VO_2	3.042	3.691	3.577	3.793	4.130	4.377	4.470	4.109	
19.									
%O_2	14.43	15.00	15.06	15.45	16.20	16.25	16.94		
%CO_2	5.20	4.80	4.80	4.80	4.40	4.50	4.00		
V_ESTPD	39.29	47.09	52.04	58.17	75.16	79.62	90.50		
VO_2	2.698	2.944	3.211	3.305	3.638	3.780	3.626		
20.									
%O_2	15.36	15.04	15.28	15.83	16.48				
%CO_2	4.85	5.20	5.05	4.90	4.40				
V_ESTPD	49.88	53.03	56.81	68.40	85.43				
VO_2	2.884	3.231	3.145	3.541	3.831				
21.									
%O_2	15.53	15.88	15.80	15.68	15.90	16.35	17.13	17.00	
%CO_2	4.30	4.10	4.40	4.55	4.60	4.20	3.40	2.80	
V_ESTPD	51.47	63.55	66.03	69.87	79.06	93.90	117.88	101.06	
VO_2	2.939	3.383	3.528	3.811	4.083	4.415	4.629	4.296	
22.									
%O_2	15.74	15.66	15.93	15.86	16.05				
%CO_2	4.40	4.55	4.40	4.55	4.20				
V_ESTPD	61.96	70.61	78.33	75.66	78.04				
VO_2	3.358	3.873	4.055	3.957	3.965				
23.									
%O_2	15.81	15.38	15.25	15.39	15.58	15.75	16.05		
%CO_2	4.20	4.60	4.70	4.60	4.60	4.60	4.50		
V_ESTPD	46.64	49.41	56.01	63.35	70.30	79.15	82.75		
VO_2	2.512	2.877	3.338	3.681	3.915	4.238	4.139		
24.									
%O_2	14.33	13.70	15.00	14.93	14.93	15.24	16.00	16.84	
%CO_2	5.30	5.60	5.10	5.20	5.30	5.20	4.80	4.10	
V_ESTPD	46.78	43.69	63.24	67.34	68.86	79.37	97.28	121.36	
VO_2	3.258	3.359	3.903	4.198	4.273	4.635	4.850	4.986	

Subject	0%	$2\frac{1}{2}$%	5%	$7\frac{1}{2}$%	10%	$12\frac{1}{2}$%	15%	$17\frac{1}{2}$%
25.								
$\%O_2$	16.14	16.25	16.38	16.75	16.95	17.20		
$\%CO_2$	4.40	4.20	4.10	4.00	3.95	3.70		
V_ESTPD	49.55	66.20	86.40	90.27	101.57	118.09		
VO_2	2.435	3.197	4.053	3.835	4.072	4.440		
26.								
$\%O_2$	15.98	15.45	15.83	15.73	15.95	15.94	16.43	16.98
$\%CO_2$	4.15	4.30	4.35	4.40	4.60	4.60	4.50	3.80
V_ESTPD	60.93	62.68	73.60	83.43	84.88	87.51	103.98	103.31
VO_2	3.158	3.644	3.916	4.533	4.330	4.476	4.700	4.143
27.								
$\%O_2$	14.55	15.65	14.68	14.63	15.25	15.03	15.70	
$\%CO_2$	5.00	4.85	5.15	5.20	4.85	5.20	4.85	
V_ESTPD	42.81	51.15	51.79	49.28	71.24	73.45	86.34	
VO_2	2.897	2.769	3.399	3.258	4.217	4.485	4.621	
28.								
$\%O_2$	15.45	15.88	15.60	15.76	16.25	16.53	16.88	
$\%CO_2$	4.50	4.10	4.55	4.60	4.30	4.15	3.85	
V_ESTPD	45.71	59.39	61.78	67.14	88.13	90.37	101.17	
VO_2	2.633	3.160	3.394	3.587	4.232	4.054	4.172	
29.								
$\%O_2$	15.13	15.46	15.68	15.88	16.28	16.78	17.05	
$\%CO_2$	4.70	4.50	4.40	4.20	4.10	3.70	3.15	
V_ESTPD	52.01	64.46	75.60	87.06	104.07	126.36	105.54	
VO_2	3.179	3.704	4.155	4.610	5.013	5.420	4.321	
30.								
$\%O_2$			15.83	17.03	17.16	17.36	17.58	17.68
$\%CO_2$			4.40	4.20	3.65	3.65	3.40	3.00
V_ESTPD			48.36	76.34	81.21	89.78	101.34	112.68
VO_2			2.565	2.933	3.103	3.204	3.403	3.759
31.								
$\%O_2$	16.00	15.15	15.83	16.20	16.66	16.58		
$\%CO_2$	3.50	4.10	4.20	4.10	4.30	3.55		
V_ESTPD	67.80	66.08	81.17	92.00	107.90	86.67		
VO_2	3.613	4.128	4.351	4.524	4.620	3.971		
32.								
$\%O_2$	16.15	15.40	16.20	15.96	16.38	16.80		
$\%CO_2$	4.05	4.60	4.20	4.40	4.30	3.75		
V_ESTPD	52.01	51.19	65.18	67.02	77.69	82.48		
VO_2	2.598	2.968	3.188	3.446	3.603	3.507		
33.								
$\%O_2$	16.00	15.80	16.65	16.95	17.33	17.55		
$\%CO_2$	3.95	4.10	3.70	3.60	3.40	2.85		
V_ESTPD	45.70	50.99	67.90	76.00	88.28	86.98		
VO_2	2.381	2.765	3.024	3.116	3.243	3.081		

Subject	0%	$2\frac{1}{2}$%	5%	$7\frac{1}{2}$%	10%	$12\frac{1}{2}$%	15%	$17\frac{1}{2}$%	20%
34.									
$\%O_2$	14.68	14.25	14.18	14.81	15.63	16.94			
$\%CO_2$	5.30	5.60	5.85	5.60	5.10	4.30			
V_ESTPD	47.01	49.78	51.44	64.99	77.80	95.90			
VO_2	3.066	3.479	3.605	4.080	4.181	3.769			
35.									
$\%O_2$	15.09	15.25	15.10	15.49	16.09	16.38	17.05	16.68	
$\%CO_2$	4.80	4.60	4.80	4.75	4.40	4.25	3.60	2.60	
V_ESTPD	40.55	60.30	60.54	68.10	82.54	92.13	110.36	83.90	
VO_2	2.487	3.609	3.707	3.843	4.108	4.285	4.387	3.949	
36.									
$\%O_2$	15.11	14.96	14.83	15.21	15.80	16.33	17.05		
$\%CO_2$	4.60	4.60	4.80	4.65	4.60	4.10	3.90		
V_ESTPD	52.93	54.58	58.50	68.58	82.07	95.64	108.79		
VO_2	3.262	3.467	3.784	4.131	4.342	4.545	4.238		
37.									
$\%O_2$	15.08	15.48	15.54	15.94	16.68	16.93	17.06	17.25	
$\%CO_2$	4.50	4.30	4.50	4.50	4.05	4.00	3.80	3.10	
V_ESTPD	30.80	47.03	57.35	63.79	76.46	80.20	90.93	86.68	
VO_2	1.918	2.717	3.237	3.280	3.305	3.224	3.555	3.341	
38.									
$\%O_2$	15.90	15.94	15.81	16.01	16.30	16.55	17.01	17.18	
$\%CO_2$	4.20	4.00	4.20	4.20	4.20	3.90	3.65	3.20	
V_ESTPD	63.34	67.89	70.25	75.51	90.28	96.98	112.50	115.52	
VO_2	3.339	3.579	3.782	3.876	4.302	4.391	4.513	4.524	
39.									
$\%O_2$	16.13	16.28	16.44	16.37	16.72	16.83	16.91		
$\%CO_2$	4.05	3.80	3.70	3.70	3.70	3.60	3.55		
V_ESTPD	56.51	64.57	69.91	79.82	95.44	103.08	103.40		
VO_2	2.835	3.162	3.299	3.838	4.166	4.383	4.307		
40.									
$\%O_2$	15.66	15.75	15.85	16.08	16.58	17.13	17.53		
$\%CO_2$	4.40	4.30	4.40	4.60	4.40	3.80	3.30		
V_ESTPD	50.63	56.98	62.97	71.77	87.37	101.85	110.20		
VO_2	2.582	3.095	3.325	3.542	3.807	3.891	3.800		
41.									
$\%O_2$	15.40	15.23	15.28	15.24	15.84	16.00	16.14	16.45	17.13
$\%CO_2$	4.60	4.60	4.55	4.70	4.40	4.30	4.50	4.20	3.40
V_ESTPD	50.60	54.51	59.40	66.10	79.06	87.35	97.74	111.62	109.75
VO_2	2.933	3.278	3.542	3.948	4.185	4.470	4.777	5.077	4.309
42.									
$\%O_2$	15.70	15.89	15.98	16.15	16.19	16.60	16.88	17.01	
$\%CO_2$	4.40	4.30	4.30	4.10	4.40	4.00	3.70	3.10	
V_ESTPD	64.77	71.92	82.70	89.63	98.91	110.33	121.34	113.12	
VO_2	3.543	3.781	4.253	4.465	4.799	4.897	5.052	4.703	

Subject	0%	2½%	5%	7½%	10%	12½%	15%	17½%	20%	22½%
43.										
%O_2	15.28	15.51	16.05	16.20	16.31	16.60	16.73			
%CO_2	4.80	4.70	4.40	4.35	4.50	4.30	4.25			
V_ESTPD	44.28	50.42	61.49	70.48	79.33	89.42	92.47			
VO_2	2.611	2.838	3.091	3.418	3.706	3.898	3.891			
44.										
%O_2	16.41	16.54	16.66	17.10	17.43	17.60				
%CO_2	4.10	4.05	3.85	3.60	3.40	2.40				
V_ESTPD	70.33	82.25	93.95	106.29	103.76	100.54				
VO_2	3.272	3.701	4.136	4.159	3.682	3.616				
45.										
%O_2	14.91	15.25	15.25	15.60	15.78	16.03	16.68	16.95		
%CO_2	4.90	4.80	4.90	4.90	4.90	4.80	4.00	3.00		
V_ESTPD	56.18	61.59	66.83	71.15	76.16	85.04	90.85	104.45		
VO_2	3.559	3.655	3.947	3.887	3.509	4.207	3.939	4.450		
46.										
%O_2	15.80	15.40	15.48	15.50	15.88	16.35	16.70	16.38		
%CO_2	4.25	4.50	4.75	5.00	4.90	4.50	4.10	3.40		
V_ESTPD	51.97	54.24	58.31	64.74	76.24	87.57	97.39	74.12		
VO_2	2.797	3.158	3.299	3.604	3.895	4.047	4.173	3.614		
47.										
%O_2	14.33	14.96	14.99	14.74	15.30					
%CO_2	5.40	5.30	5.20	5.50	5.20					
V_ESTPD	60.12	59.88	71.75	77.58	83.81					
VO_2	4.171	3.694	4.418	4.961	4.832					
48.										
%O_2	13.98	13.58	13.81	13.63	13.73	14.49	15.24	15.93	16.43	15.98
%CO_2	5.10	5.35	5.30	5.95	5.75	5.50	5.30	4.80	4.30	3.60
V_ESTPD	39.35	36.84	43.70	39.40	50.72	65.59	77.96	93.25	105.90	84.75
VO_2	2.936	2.910	3.331	3.025	3.858	4.400	4.532	4.730	4.843	4.516

RAW SCORES OBTAINED ON THE
MODIFIED ASTRAND BICYCLE ERGOMETER
TEST OF MAXIMAL OXYGEN UPTAKE

Work Level Expressed in Kilopond Meters per Minute

Subject	900	1200	1500	1800	1950	2100
1.						
$\%O_2$	15.88	15.35	15.90	16.63		
$\%CO_2$	4.40	4.80	4.50	4.00		
V_ESTPD	40.51	52.29	78.36	93.62		
VO_2	2.123	3.036	4.069	4.119		
2.						
$\%O_2$	16.28	16.70	16.93	16.95		
$\%CO_2$	4.20	4.00	4.00	3.40		
V_ESTPD	52.71	79.53	99.19	94.97		
VO_2	2.525	3.429	3.988	3.944		
3.						
$\%O_2$	15.98	16.25	17.20	17.51		
$\%CO_2$	4.40	4.40	3.70	3.05		
V_ESTPD	44.06	62.15	100.95	111.75		
VO_2	2.254	2.967	3.794	3.954		
4.						
$\%O_2$	15.48	16.28	16.61	17.73		
$\%CO_2$	4.80	4.30	4.10	2.60		
V_ESTPD	45.80	74.10	91.19	118.44		
VO_2	2.584	3.531	4.011	4.003		
5.						
$\%O_2$	17.04	16.75	17.63	17.58		
$\%CO_2$	3.80	4.20	3.50	3.10		
V_ESTPD	57.13	70.48	107.66	96.01		
VO_2	2.247	2.957	3.517	3.299		
6.						
$\%O_2$	17.95	17.68	17.68	17.70		
$\%CO_2$	3.05	3.20	3.30	2.70		
V_ESTPD	85.52	108.94	131.42	111.51		
VO_2	2.551	3.577	4.280	3.780		
7.						
$\%O_2$	15.76	15.33	15.93	16.80	17.00	
$\%CO_2$	4.80	5.20	4.80	3.75	3.50	
V_ESTPD	47.33	58.31	84.59	107.56	122.64	
VO_2	2.502	3.338	4.292	4.572	4.985	
8.						
$\%O_2$	15.36	15.55	17.06	16.23		
$\%CO_2$	4.60	4.65	3.70	3.40		
V_ESTPD	44.96	69.62	105.99	57.79		
VO_2	2.628	3.895	4.171	2.927		

Subject	900	1200	1500	1800	1950	2100
9.						
$\%O_2$	15.88	16.53	17.50	16.73		
$\%CO_2$	4.55	4.20	3.00	2.85		
$V_E STPD$	51.00	83.61	101.35	69.49		
VO_2	2.654	3.740	3.612	3.181		
10.						
$\%O_2$	13.68	13.69	14.80	15.80	15.53	
$\%CO_2$	6.05	5.85	5.80	4.80	4.10	
$V_E STPD$	31.10	50.05	68.03	84.52	71.38	
VO_2	2.360	3.819	4.244	4.428	4.115	
11.						
$\%O_2$	15.21	15.13	16.03	16.95		
$\%CO_2$	4.50	4.90	4.60	3.60		
$V_E STPD$	36.15	45.18	82.78	99.96		
VO_2	2.193	2.738	4.140	4.099		
12.						
$\%O_2$	15.70	15.98	16.93	17.20		
$\%CO_2$	4.65	4.45	3.80	2.75		
$V_E STPD$	46.01	67.92	95.94	81.86		
VO_2	2.486	3.465	3.908	3.284		
13.						
$\%O_2$	14.98	16.06	17.04	16.53		
$\%CO_2$	4.65	4.30	3.65	3.20		
$V_E STPD$	32.82	67.12	112.88	80.15		
VO_2	2.073	3.384	4.486	3.798		
14.						
$\%O_2$	17.01	16.58				
$\%CO_2$	3.60	3.30				
$V_E STPD$	75.59	61.72				
VO_2	3.042	2.869				
15.						
$\%O_2$	15.75	17.03	17.63	17.05		
$\%CO_2$	4.70	3.70	3.20	3.20		
$V_E STPD$	44.83	76.33	101.51	89.19		
VO_2	2.387	3.033	3.398	3.639		
16.						
$\%O_2$	15.78	15.13	16.36	17.10		
$\%CO_2$	4.60	5.00	4.60	3.30		
$V_E STPD$	41.94	55.67	93.04	99.79		
VO_2	2.229	3.358	4.263	3.983		
17.						
$\%O_2$	16.01	15.85	16.83	16.74		
$\%CO_2$	4.20	4.60	3.60	3.50		
$V_E STPD$	51.38	66.76	109.98	102.64		
VO_2	2.636	3.490	4.677	4.510		

Subject	900	1200	1500	1800	1950	2100
18.						
$\%O_2$	16.65	17.03	17.48	16.93		
$\%CO_2$	3.80	3.45	3.20	2.85		
V_ESTPD	63.08	88.88	116.14	76.71		
VO_2	2.792	3.590	4.108	3.319		
19.						
$\%O_2$	15.75	16.63	16.53	16.29		
$\%CO_2$	4.40	4.00	3.90	3.50		
V_ESTPD	42.68	77.16	78.24	65.11		
VO_2	2.307	3.395	3.561	3.231		
20.						
$\%O_2$	17.53	16.94	15.86			
$\%CO_2$	3.40	3.20	3.50			
V_ESTPD	83.33	69.54	41.50			
VO_2	2.850	2.934	2.286			
21.						
$\%O_2$	15.43	16.13	17.21	17.23		
$\%CO_2$	4.50	4.40	3.05	2.80		
V_ESTPD	43.15	67.97	106.88	82.08		
VO_2	2.497	3.349	4.188	3.250		
22.						
$\%O_2$	15.59	16.33	16.40	16.95		
$\%CO_2$	4.90	4.50	4.30	3.40		
V_ESTPD	46.35	71.39	86.28	85.57		
VO_2	2.538	3.318	3.978	3.555		
23.						
$\%O_2$	14.85	16.14	16.20	16.92		
$\%CO_2$	5.20	4.45	4.20	3.10		
V_ESTPD	37.09	63.88	75.55	70.97		
VO_2	2.349	3.131	3.694	3.031		
24.						
$\%O_2$	15.08	14.68	16.68	16.68	17.38	
$\%CO_2$	5.20	5.55	4.35	3.60	3.00	
V_ESTPD	36.76	48.25	96.54	91.44	72.10	
VO_2	2.221	3.115	4.098	4.063	2.680	

Subject	900	1200	1500	1800	1950	2100
25.						
$\%O_2$	15.25	15.78	16.35	15.93		
$\%CO_2$	4.70	4.50	3.60	4.00		
$V_E STPD$	45.88	62.63	67.76	60.70		
VO_2	2.734	3.347	3.292	3.209		
26.						
$\%O_2$	15.90	16.50	17.00			
$\%CO_2$	4.20	3.80	3.60			
$V_E STPD$	51.71	79.34	115.32			
VO_2	2.730	3.663	4.657			
27.						
$\%O_2$	14.75	15.35	15.25	14.80		
$\%CO_2$	5.30	4.95	4.65	4.00		
$V_E STPD$	42.50	62.22	66.93	49.64		
VO_2	2.735	3.589	3.999	3.333		
28.						
$\%O_2$	16.05	15.90	17.53	17.70		
$\%CO_2$	3.80	4.75	3.20	2.80		
$V_E STPD$	25.66	65.02	114.11	118.87		
VO_2	1.330	3.331	3.964	4.000		
29.						
$\%O_2$	15.93	16.80	16.48	15.93		
$\%CO_2$	4.50	3.90	4.00	3.75		
$V_E STPD$	45.60	84.69	86.69	69.55		
VO_2	2.349	3.567	3.979	3.723		
30.						
$\%O_2$	16.69	16.95	17.20	17.38		
$\%CO_2$	3.90	3.80	3.55	2.90		
$V_E STPD$	57.95	70.80	74.29	72.68		
VO_2	2.522	2.867	2.822	2.719		
31.						
$\%O_2$	16.50	16.93	16.80			
$\%CO_2$	3.75	3.70	3.20			
$V_E STPD$	58.85	86.01	81.41			
VO_2	2.726	3.526	3.580			
32.						
$\%O_2$	15.20	16.58	16.60	16.63		
$\%CO_2$	5.15	4.00	3.60	3.00		
$V_E STPD$	40.68	71.60	68.30	58.95		
VO_2	2.402	3.195	3.105	2.750		
33.						
$\%O_2$	17.38	16.93	17.08			
$\%CO_2$	3.40	4.00	3.40			
$V_E STPD$	57.49	71.54	55.87			
VO_2	2.076	2.877	2.230			

Subject	900	1200	1500	1800	1950	2100
34.						
%O_2	15.46	16.41	17.15	17.01		
%CO_2	4.90	4.15	3.45	2.80		
V_ESTPD	46.31	75.73	96.55	81.27		
VO_2	2.613	3.512	3.753	3.443		
35.						
%O_2	14.68	16.66	16.96	17.18		
%CO_2	5.05	4.05	3.60	2.65		
V_ESTPD	37.97	81.89	89.17	88.78		
VO_2	2.503	3.561	3.645	3.606		
36.						
%O_2	14.58	14.55	15.88	16.88	16.44	
%CO_2	5.35	5.30	4.70	3.80	3.45	
V_ESTPD	34.31	51.66	84.05	108.06	88.33	
VO_2	2.276	3.454	4.339	4.471	4.228	
37.						
%O_2	15.88	16.28	17.23			
%CO_2	4.40	4.40	3.70			
V_ESTPD	46.54	64.47	89.41			
VO_2	2.441	3.055	3.328			
38.						
%O_2	14.78	15.55	16.50	16.95		
%CO_2	5.10	5.00	4.30	3.60		
V_ESTPD	39.53	60.35	94.64	103.42		
VO_2	2.649	3.320	4.217	4.242		
39.						
%O_2	15.54	16.60	17.14			
%CO_2	4.70	4.00	3.20			
V_ESTPD	50.43	78.87	73.68			
VO_2	2.822	3.500	2.923			
40.						
%O_2	15.44	15.01	16.75	16.68		
%CO_2	5.10	4.15	3.40	3.65		
V_ESTPD	45.40	71.33	79.12	53.59		
VO_2	2.549	4.576	3.487	2.780		
41.						
%O_2	15.11	16.00	16.55	16.15		
%CO_2	4.95	4.65	4.10	3.45		
V_ESTPD	39.03	68.67	87.77	66.07		
VO_2	2.370	3.455	3.928	3.406		
42.						
%O_2	15.63	15.78	16.05	16.75	16.96	
%CO_2	4.65	4.55	4.30	3.90	3.20	
V_ESTPD	44.50	62.34	82.46	121.87	117.38	
VO_2	2.445	3.321	4.168	5.209	4.923	

Subject	900	1200	1500	1800	1950	2100
43.						
$\%O_2$	15.51	16.85	16.70	17.03		
$\%CO_2$	4.70	3.70	3.50	3.00		
$V_E STPD$	43.16	76.56	72.45	76.43		
VO_2	2.429	3.217	3.221	3.179		
44.						
$\%O_2$	15.73	16.10	16.80	16.48		
$\%CO_2$	4.70	4.30	3.75	3.60		
$V_E STPD$	52.81	72.69	84.63	65.70		
VO_2	2.827	3.627	3.598	3.190		
45.						
$\%O_2$	15.26	15.06	16.40	16.00		
$\%CO_2$	4.90	5.15	4.50	3.40		
$V_E STPD$	45.01	52.93	90.22	64.80		
VO_2	2.655	3.219	4.113	3.471		
46.						
$\%O_2$	15.38	15.70	15.98	16.14		
$\%CO_2$	5.00	4.80	4.90	3.90		
$V_E STPD$	42.79	60.08	70.50	73.13		
VO_2	2.446	3.224	3.514	3.690		
47.						
$\%O_2$	13.98	13.86	14.55	16.30	16.25	
$\%CO_2$	4.90	5.70	5.60	4.60	3.80	
$V_E STPD$	39.87	42.29	65.88	85.99	82.07	
VO_2	2.995	3.151	4.352	4.005	4.050	
48.						
$\%O_2$	14.05	14.69	16.50	16.50		
$\%CO_2$	5.40	5.25	4.00	3.80		
$V_E STPD$	35.00	45.29	95.79	96.48		
VO_2	2.552	2.954	4.372	4.455		